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NRL Memorandum Report 896

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# **SPACE SURVEILLANCE SYSTEM**

## **TECHNICAL SUMMARY REPORT NO. 1**

ARPA Order No. 7-58

Applications Research Division

December 31, 1958

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**U. S. NAVAL RESEARCH LABORATORY**  
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TO: Mr. Chuck Rogers, Code 1221

REF: (a) NRL Memorandum Report 896 dtd December 31, 1958

1. As requested by Dr. van Keuren, I have reviewed the report of reference (a). This report describes the early development of what became the Naval Space Surveillance System. The descriptions and data were once classified, but have long since been unclassified. Additionally, the system itself has been extensively modified over the years to where this report is no longer accurate.
2. For these reasons, I can see no need to limit the distribution of this report. It is of historical interest but no longer an accurate description of the operational one.

*R.L. Beard*

R.L. Beard, Head  
Space Applications  
Branch

Copy to: Dr. van Keuren, Code 1232

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## **ABSTRACT**

A program to develop and install a system to detect and track non-radiating satellites was assigned to the Naval Research Laboratory in June 1958 by ARPA. Initially the program involved a feasibility experiment using a 50-kw continuous-wave transmitter and a Minitrack receiving system about 250 miles away. Both transmitting and receiving antennas were 400 feet long. The transmitter illuminates objects in space, and reflections to the receivers permit direction of arrival to be determined by an interferometer method. This system first gave a well-established reflection on 1958 Delta 2 on August 7, 1958.

Steps taken to provide an operational capability include (1) adding a second receiver station to form a 3-station complex in the eastern part of the southern U.S. with the transmitter in the center, and (2) reproducing the complex in the western part of the U.S., with all six stations on a great circle. The full Eastern Complex has been operating since November 30, 1958. The Western Complex should be operating in January 1959.

Early results indicated the desirability for larger antennas to extend the system range. The western transmitter will use a 1600-foot antenna and one is programmed for the eastern transmitter in early February 1959. Site acquisition and planning at all stations have been based on a future need for larger antennas. The Fort Stewart receiving site, in the Eastern Complex, will receive a 1600-foot detection system in the next few months. It will also be provided with 400-foot sections whose polarization is at right angles to the main beam in order to evaluate the loss of signals resulting from polarization rotation in passing through the ionosphere.

The receiving stations record signals continuously. This information is analyzed to evaluate the system by correlating signals with known satellite data. Correlations have been based upon time-and-look-angle correspondence with predicted passes. Only recently has the system performance been established to the point where precise analysis can be applied. The full operation of the Eastern Complex now permits height determination by triangulation, indicating excellent results in the case of the 1958 Zeta data analyzed to date.

## **PROBLEM STATUS**

This is the first Semiannual Technical Summary Report covering work from the date of the ARPA Order through December 31, 1958. Work is continuing.

## **AUTHORIZATION**

NRL Problem R02-35  
ARPA Order No. 7-58

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## SPACE SURVEILLANCE SYSTEM TECHNICAL SUMMARY REPORT NO. 1

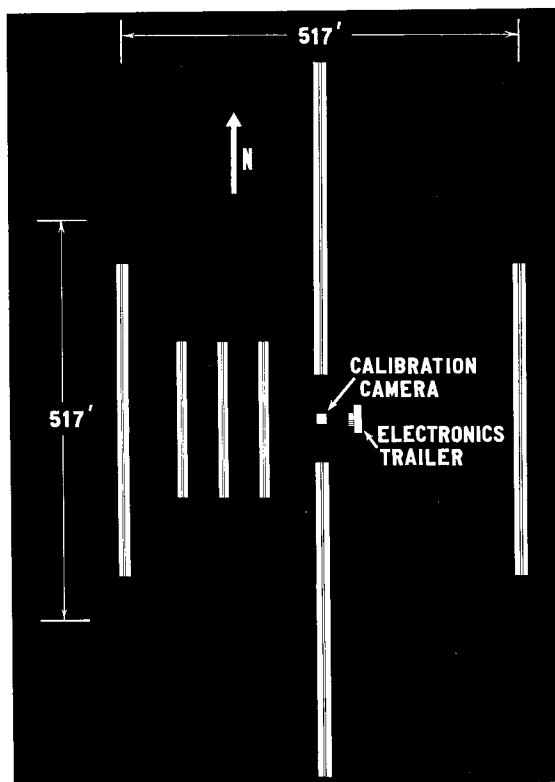
### BACKGROUND

#### Initial Concept

When the U.S. earth satellite program was first proposed, one of the most difficult problems facing this program was that of proving the existence of the satellite. This problem was solved by the use of a system which measured the angle of arrival of the received signal and is called Minitrack. The initial parameters of the system were selected within an hour of its inception and now vary only insignificantly from the values initially selected. This system has proved to be reliable and accurate.

When the problem of detecting dark objects was first encountered it was initially thought to be so difficult as to be essentially insolvable. The system proposed by this Laboratory depended on a Minitrack receiving system modified to utilize large antennas and an illuminating transmitter, the antenna beams being so oriented that they overlap. Figure 1 is a drawing of the original concept for that antenna layout at a receiving station. The antennas are eight times as long as those used for the original Minitrack - otherwise the layouts are very nearly identical.

Fig. 1 - Original concept of arrangement of receiving stations showing 400-foot antennas



Although both tracking systems are similar, the plan of original Minitrack changed very little during its development while the concept of the active system has changed greatly. The reason for this change in development is that the problem of detecting dark satellites is much more difficult since its detection range is governed by the fourth power law while for the original Minitrack the square law applied.

Other difficulties encountered only by the new system are (1) the presence of great numbers of false echoes which must be eliminated by using additional receiving sites in triangulation nets, (2) more noisy signals due to the small amount of reflected power which have necessitated using more and still longer antennas, (3) unjustified optimism in the sensitivity of the receiving system. Failure to obtain expected sensitivity was a result of (1) the short receiving time available and (2) the necessity for providing the capability of receiving cross-polarized signals due to the rotation of the plane of polarization of the signal between transmission and reception.

The result of these difficulties has been that the cost of the system has increased to nearly double the original estimate. The original concept of the system involved Complexes located in the southern U.S. (Fig. 2) each consisting of two receivers spaced about 500 miles apart with a transmitter between. This concept was then changed so all stations are located on a single great circle as shown in Fig. 3 to permit possible future illumination for all receiving stations by a single centrally located transmitter.

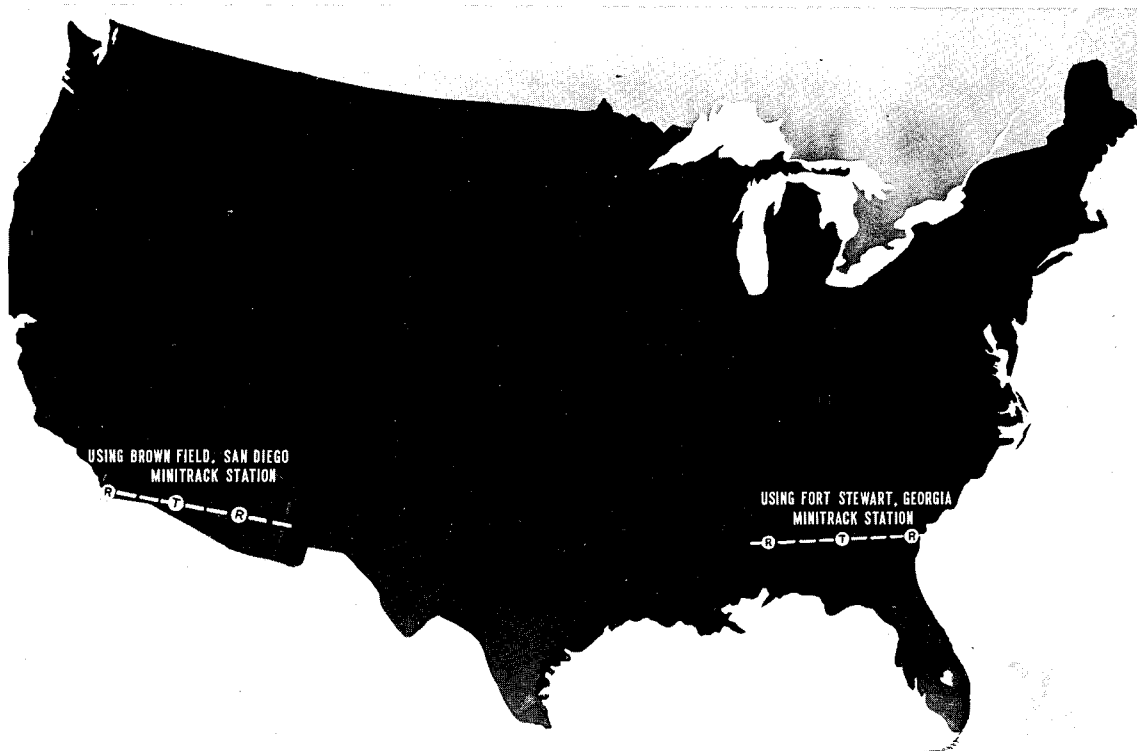


Fig. 2 - Complex locations initially proposed

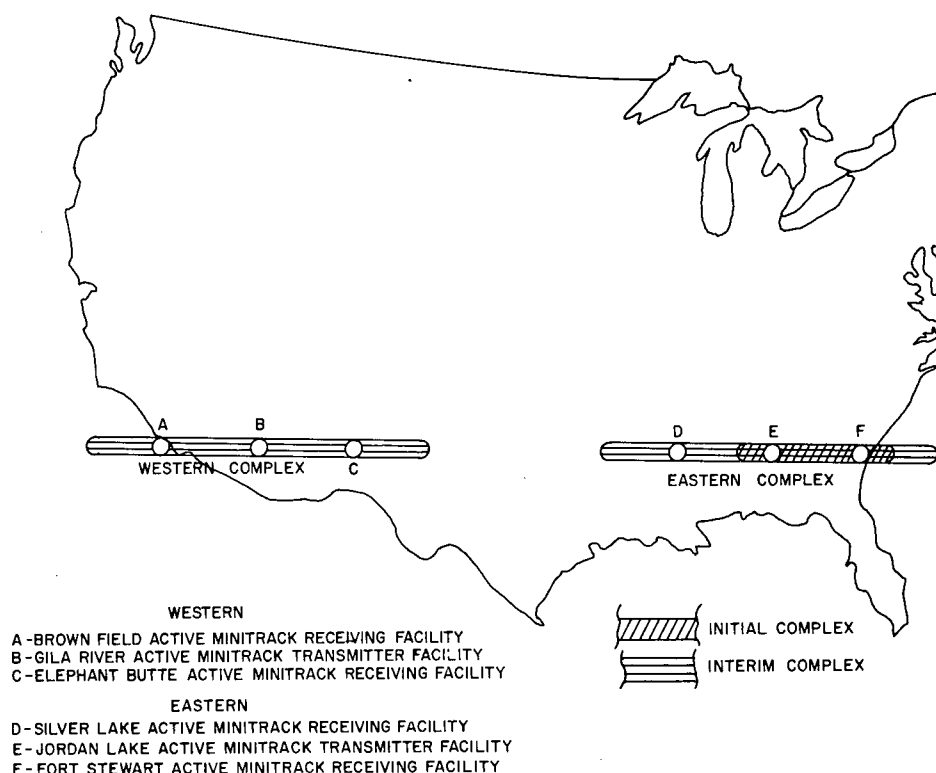


Fig. 3 - Eastern and Western Complexes of active Minitrack system as built

### Feasibility Installation

The original installation used the Minitrack receiving trailer with three 400-foot antennas located at Fort Stewart and a 50-kw transmitter located near Wetumpka, Ala., about 250 miles away, exciting a 400-foot antenna to provide a minimum feasibility operation. All the dipole elements of these antennas were aligned in an east-west direction.

The three antennas at Fort Stewart were separated by distances of 52.2 and 57.4 feet giving (direct and difference) baselines of 5.2, 52.2, 57.4, and 109.6 feet.

For the transmitter, eight normal Minitrack arrays, taken largely from the original Fort Stewart installation, were connected together by means of suitably sized transmission lines to provide a 400-foot antenna with the electric vector aligned in an east-west direction.

The transmitter is one which had been used at Fort Monmouth to provide calibration signals at the Minitrack stations by reflecting signals from the moon. This transmitter had also been used to reflect signals from 1957 Beta to the Minitrack station at Blossom Point, Md., in an experiment which demonstrated the feasibility of and led to the development of this dark-satellite detection system. Figure 4 shows this transmitter as installed at Jordan Lake near Wetumpka, Alabama.

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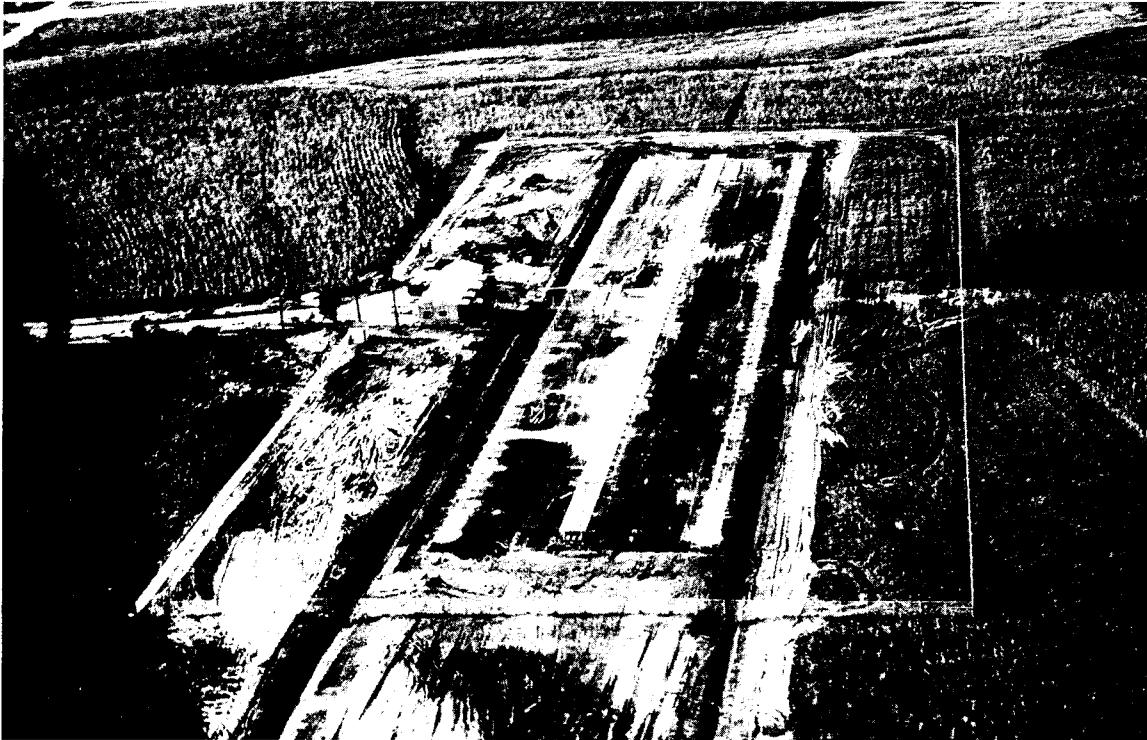


Fig. 4 - Jordan Lake transmitting site

ARPA Order No. 7-58 was dated June 20, 1958. On July 29 the Jordan Lake transmitter was turned on and on August 2 the two-station complex was placed in operation. The first well-established reflected signal was obtained on August 7 from 1958 Delta 2. This operation continued until the second receiving station at Silver Lake was activated on November 30, 1958. During this feasibility period emphasis was placed on identifying peculiar characteristics of the reflected signal and evaluating the performance of an active system.

#### SPACE SURVEILLANCE STATIONS

##### Fort Stewart Receiving Site - Initial Installation

When the data from the original Fort Stewart site was analyzed it became apparent that the shortest baseline was too long. Before the installation it was realized that the 5.2-foot baseline, being more than one-half wavelength long, could provide a somewhat ambiguous reading, especially for signals appearing from near the horizons. At the time of installation it was felt that the antenna pattern would attenuate these signals originating from the horizons by an amount sufficient to eliminate this problem. But it was soon determined that such was not the case and that a shorter baseline would definitely be needed. The 4-foot baseline selected and installed in September proved quite satisfactory but did introduce a further problem.

When the center antenna was moved to obtain a 4-foot baseline, the possible baselines then became 4, 52.8, 56.8, and 109.6 feet. The step from 4 feet to 52.8 feet was so great as to introduce further ambiguities into the system.

To eliminate these ambiguities, the installations being built at other sites were modified to provide a 20-foot baseline. Later, in December, after the Silver Lake station had shown significantly better ambiguity resolution than the Fort Stewart site, one of the antennas at Fort Stewart was moved so that the antenna spacings are now 24.4, 28.4, and 52.8 feet providing baselines 4, 24.4, 28.4, and 52.8 feet long.

#### Jordan Lake Transmitting Site

As mentioned, the Jordan Lake transmitter (Fig. 5) was previously located at Fort Monmouth. The Fort Monmouth installation was made up of a 3-kw RCA FM exciter, a 10-kw Westinghouse FM amplifier, and a 50-kw GE amplifier purchased by Vanguard for use as a moon-bounced calibration signal for the Minitrack stations.

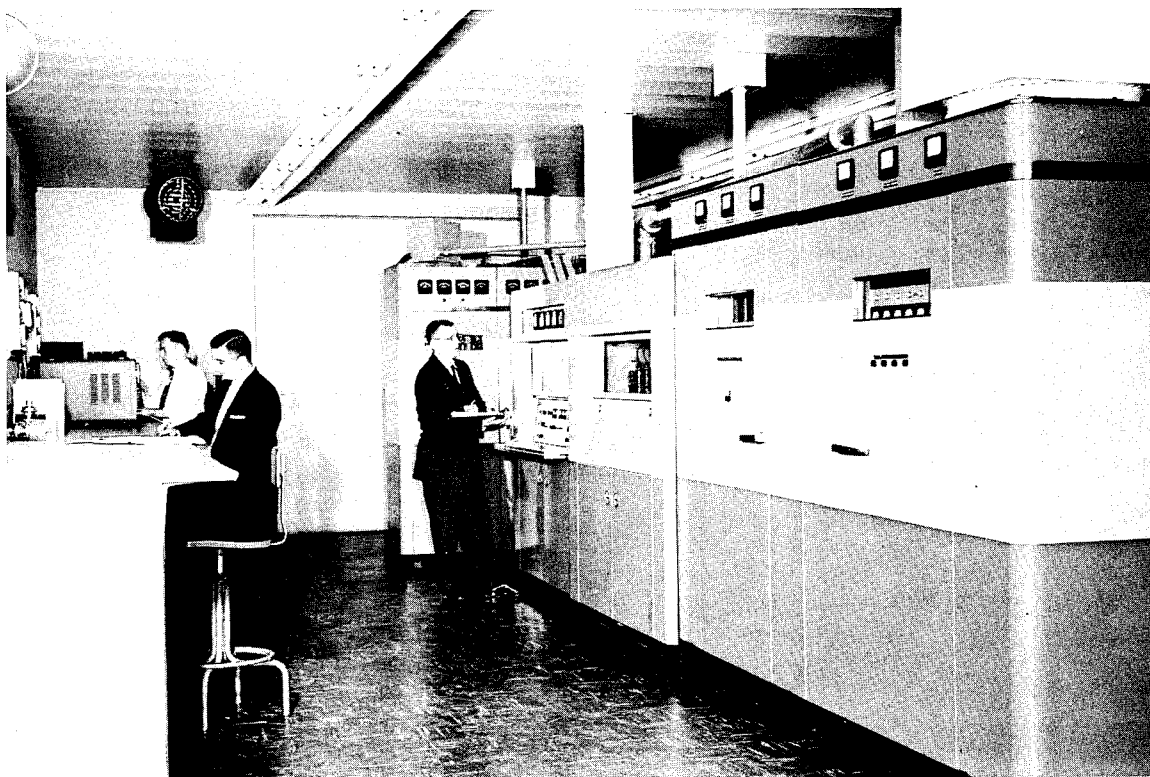


Fig. 5 - Jordan Lake transmitter

The antenna used was made up principally of elements from the Fort Stewart Minitrack arrays. These arrays were augmented by purchased elements to form a single 400-foot array shown in Fig. 4.

The elements of this 400-foot array were connected together using appropriate transmission lines. The electric vector is aligned in an east-west direction. After some of the receiving-type transmission line was modified to handle the higher power, the antenna was put into operational service. Since August 2 the antenna has operated without failure.

Despite its age, the transmitter, too, has an excellent service record with operational utilization since August 2 of better than 95 percent. To obtain this reliability the power output has been reduced from 50 kw to 40 kw.

#### Silver Lake Receiving Site

The Silver Lake Receiving Site was placed in operation on November 30, 1958. This station uses electronic equipment designed for the system and an antenna layout having features not included at the Fort Stewart site.

The layout for this station (identical to Brown Field and Elephant Butte site) is shown in Fig. 6, an aerial view is shown in Fig. 7, and the ground screen construction in Fig. 8. While the system is built to accommodate 1600-foot antennas on the shorter baselines, only 400-foot antennas are now installed. Arrays 2c, 3c, 4c, 7c, and 4b are now in place; the dipole elements of these arrays are aligned in a north-south direction. Broadside arrays to receive orthogonally polarized signals are placed at array 1 and array 5. The electronics installation, typical of all receiving sites, is shown in Fig. 9.

These arrays provide baselines of 4 feet, 20 feet, 52.8 feet, 56.8 feet, 109 feet, and 521 feet. The antenna elements are gamma-matched elements identical to those used at Fort Stewart. The connecting cables are of Styroflex instead of rigid lines as are used at Stewart; they are superior with respect to leakage of air. The rigid lines at Fort Stewart leak so badly that they will be replaced with Styroflex.

The result of these improvements is that Silver Lake data is much improved over the Fort Stewart data. Even so, further improvements to the antenna layout at this station are indicated from the data obtained, which point out the necessity for even better ambiguity resolution and better system performance.

#### Brown Field Receiving Site

The Brown Field installation was placed in operation on December 15, 1958. The electronic equipment and antenna layout is identical to that described for Silver Lake.

#### Elephant Butte Receiving Site

The Elephant Butte receiving site is likewise identical to Silver Lake. It should be in operation by January 26.

#### Gila River Transmitting Site

The Gila River transmitter site is the first site that will utilize a 1600-foot antenna. This antenna consists of 192 dipoles of a new type designed to be completely sealed with "O" rings and to require a minimum number of transmission line connections. The element (Fig. 10) has been tested to 3 kw. At Gila River the power in each element will be 250 watts.

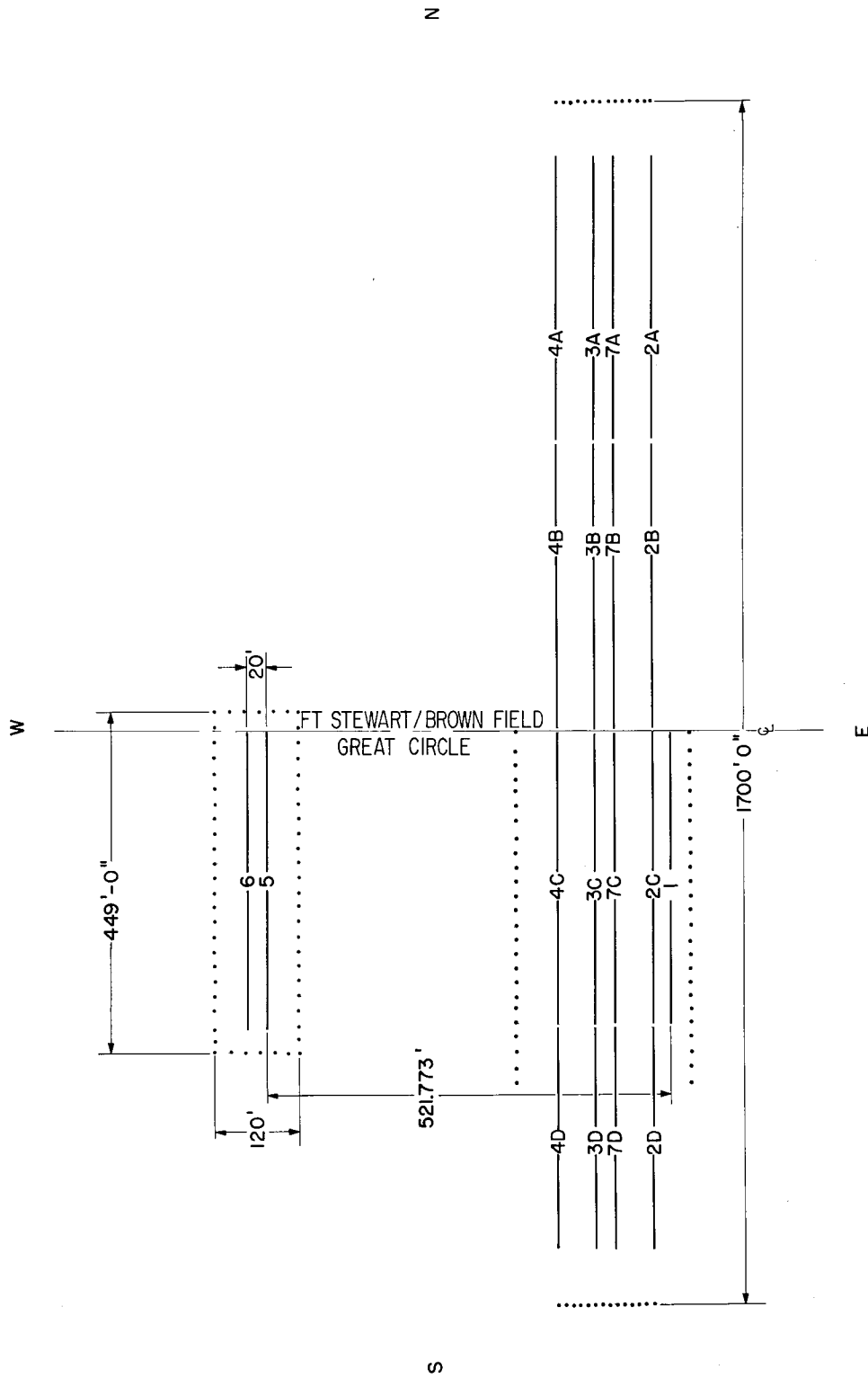


Fig. 6 - Layout plan of receiving antennas

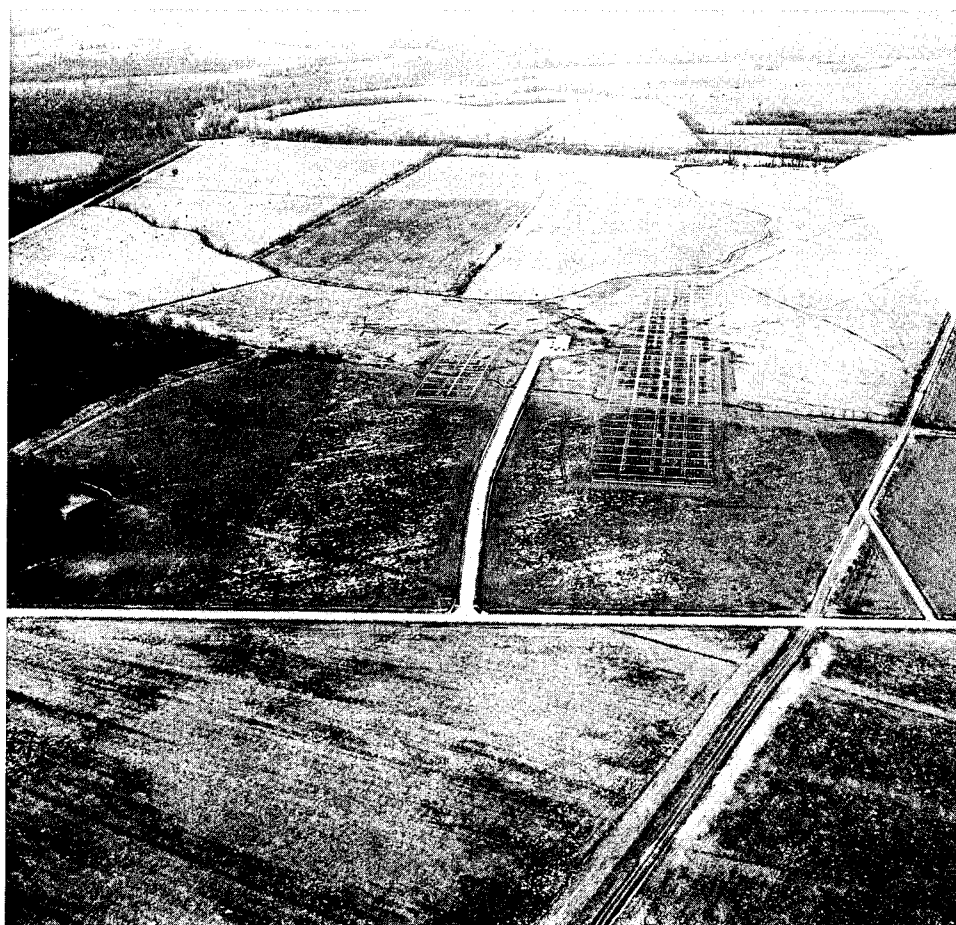


Fig. 7 - Silver Lake antenna field

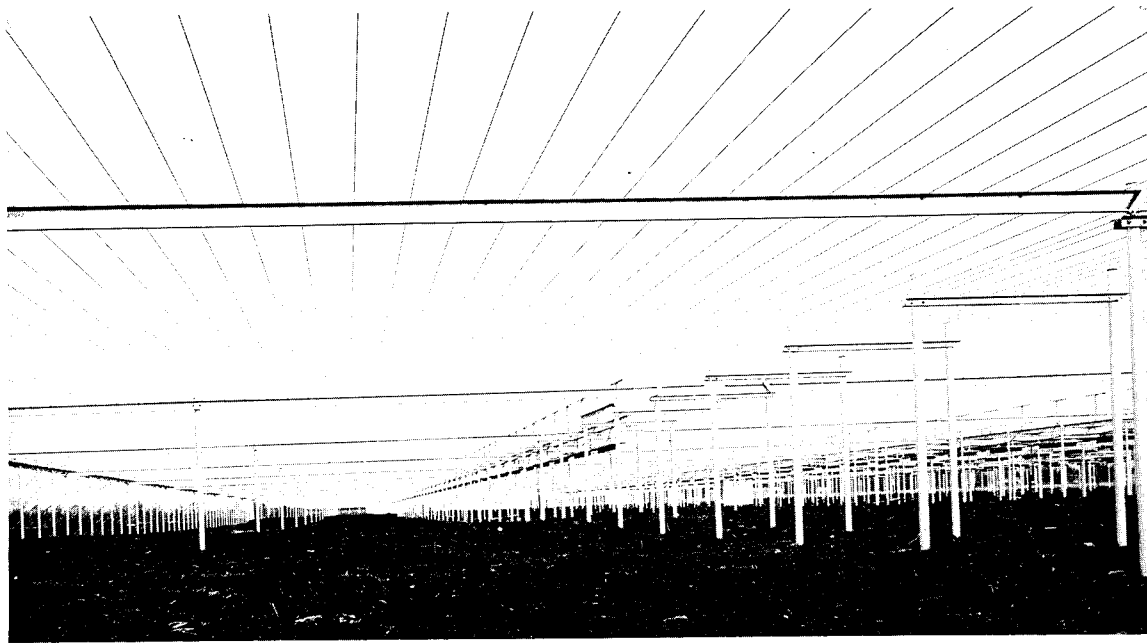


Fig. 8 - Looking up at the ground screen at Silver Lake

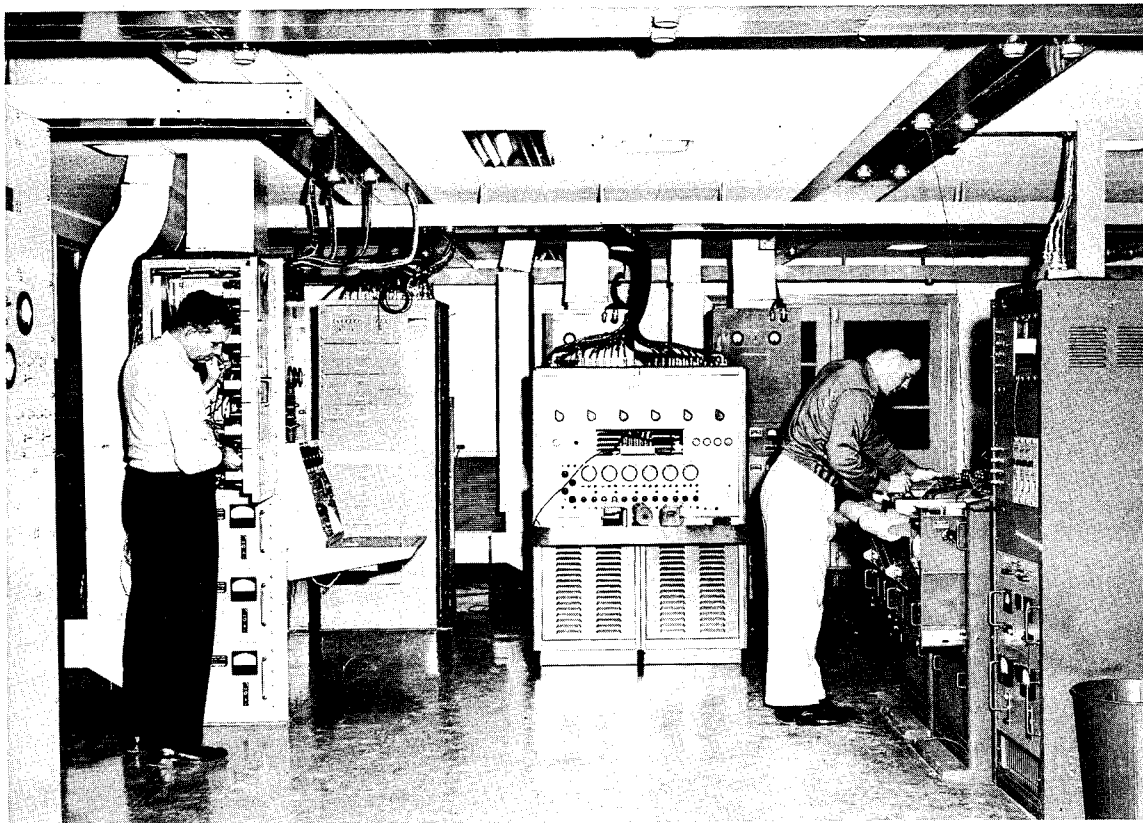


Fig. 9 - Typical receiving electronics installation - Silver Lake

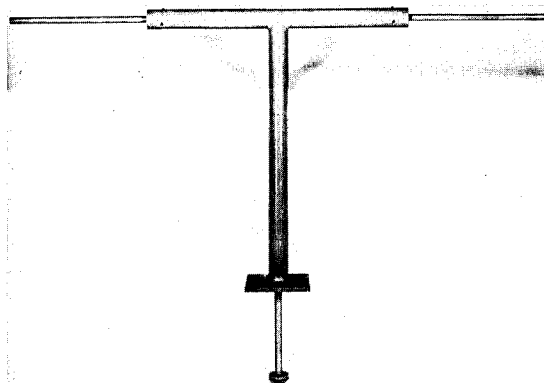


Fig. 10 - Pressurized dipole element

The transmitter consists of two 25-kw television-type units connected together to provide 50 kw and modified as necessary to operate at the 108-Mc frequency. This unit derives its frequency from a precision crystal clock corrected to WWV.

The system performance of the Western Complex should be greater than that of the Eastern Complex by about 7 db due to the improved transmitter installation. The entire Complex should be in operation by January 26.

#### New Jordan Lake Antenna

A 1600-foot antenna identical to that being installed at Gila River is scheduled to be installed at Jordan Lake by early February. This antenna will have its dipole elements all aligned in a north-south direction. Figure 11 is an aerial view of the antenna support posts.

#### New Fort Stewart Installation

The new Fort Stewart installation is designed to reflect the experience gained in the interim Eastern Complex.

Antennas 1600 feet long will be used for baselines up to 109 feet. The increase in baseline lengths will be by a factor of two, or less. The following baselines will be available: 4, 8, 16, 28, 52, 56, and 109 feet with 1600-foot antennas and 521 feet with 400-foot antennas. All baselines will have 400-foot cross-polarized antennas.

The antenna elements will be completely pressurized and will be identical to those used for the transmitting installation.

To evaluate the capability of obtaining phase-rate information, consideration is being given to a plan to move one of the present 1600-foot antennas and to install two additional 400-foot antennas. These changes would permit two-to-one baseline steps to 1851-foot baselines and would thus provide greatly increased accuracy and phase-rate information to provide angle of passage through the fence.



Fig. 11 - Jordan Lake transmitting antenna field

#### Antenna Summary Chart

Figure 12 shows the evolution of antenna arrays through December 31, 1958 for the Eastern Complex.

#### FACILITIES

##### Site Selection Criteria

In developing the criteria for the selection of the necessary real estate, consideration was given not only to the initial system's requirements but also to allow for the possibility that the future or ultimate system very likely would have expanded requirements. The initial concept consisted of placing three stations, that is, two receivers and transmitter on a great circle line, with the receivers equally spaced 200 to 250 miles east and west of the transmitter. The site selection criteria actually used gave consideration to the

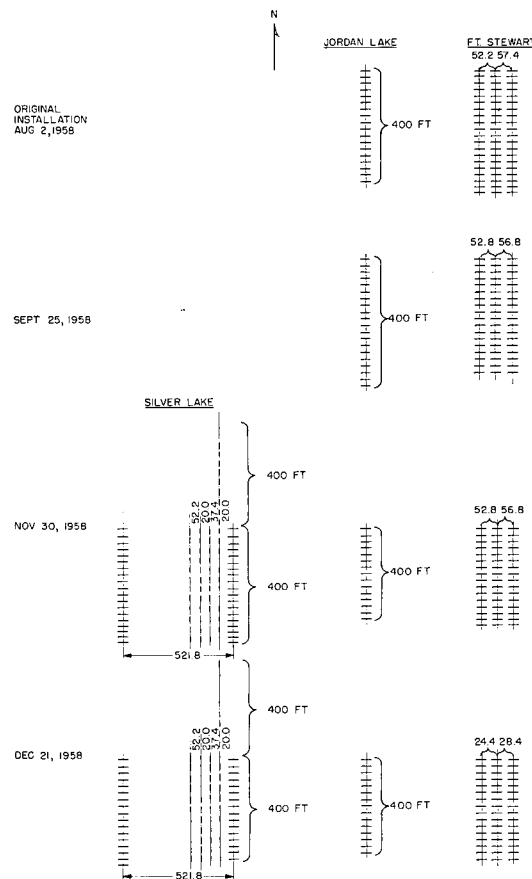


Fig. 12 - Evolution of antenna arrays through December 31, 1958

possibility that at some future date the whole east-west fence starting at Savannah, Georgia, and ending at San Diego, California, might use a single high-powered transmitter located at the midpoint of this line to illuminate the complete "fence." This, therefore, established the plane of the great circle at an inclination of about 33 degrees.

Even though the initial receiving antenna layout required only an area of about 1000 feet in the north-south direction and about 600 feet in the east-west direction, the sites selected provided for the possibility that the ultimate system requirement would demand a different type antenna layout including an increased length in the north-south direction to possibly 3200 feet. An attempt was therefore made to obtain sites 1000 feet in the east-west dimension and 3500 feet in the north-south dimension. An additional requirement that the site be essentially level was imposed in order to keep the construction cost at a minimum.

The receiver site criteria included the requirements that they be removed a minimum of two miles from high-powered transmission lines, large electrical power consumers, and areas of dense aircraft traffic. These latter requirements were imposed in order to reduce interference in the receivers. A secondary requirement that large amount of electrical power be readily available was imposed on the transmitter site criteria.

### Site Acquisition

With the exception of the Fort Stewart site and the Brown Field site, the geographical considerations made it highly doubtful that existing government owned land would be in the right position to meet the systems requirements. Considering the fact that this was an experimental system and that the earliest possible capability had to be achieved, all new sites were acquired on a temporary basis. The rights for each site are covered by an annual lease with an option by the government to renew for four additional one-year periods. If, during this total period of five years, it is determined that the system will be of a permanent type, consideration can then be given to the actual procurement of the land. The site on which the Gila River transmitter is located presented a somewhat different problem in that it happened to fall inside an Indian reservation where land could neither be bought nor leased. A special right-of-way was obtained which gave the government rights equivalent to those normally obtainable in a lease arrangement. Appendix A provides a tabulation of the detailed information concerning the sites for each of the stations. The receiving sites as chosen are about 280 statute miles from the transmitting sites.

### Facilities Planning and Construction

Feasibility Installation. Since it was extremely urgent that the feasibility of the detection and tracking technique be established, the 6th Naval District Public Works Officer was requested to select an architectural engineering firm (Sherlock, Smith and Adams of Montgomery, Ala. received the contract) to assist in the site selection and the necessary design and planning for the installation. At the same time this firm acted as a sub-contractor to both antenna contractor (TACO) and to the transmitter contractor (MULTRONICS) with the responsibility to construct both the antenna field and the transmitter building. This procedure made it possible to turn on the 50-kw transmitter on a newly acquired site near Jordan Lake by July 29, 1958 (approximately five weeks after issuance of ARPA Order 7-58). The system became operational on August 2, 1958.

Three new antennas were installed by TACO and the Army at Fort Stewart and were in use on July 29, 1958.

Initial System. In order to simplify the design process for the various stations, the 11th Naval District assumed the responsibility to develop the basic architectural and engineering drawings for a receiver site. They engaged an architectural engineering firm in Phoenix, Arizona, to do this work from the Gila River transmitter station. These designs were then site adapted by 8th Naval District, the 6th Naval District, and the Army Engineers for their local station requirements. The Army Engineers assumed full responsibility for the construction of the new Fort Stewart receiver station. The 6th Naval District assumed responsibility for the construction of the new Jordan Lake transmitter and the Silver Lake receiving installation, and the 8th Naval District assumed responsibility for the Elephant Butte receiving installation. By using this technique all the efforts of the Laboratory were directed toward coordinating the design with the 11th Naval District. As soon as these drawings were completed and approved, the other constructing agencies were then given complete responsibility to site-adapt these drawings without any further reference to the Laboratory. Liaison, however, was maintained by the Laboratory with the individual District Public Works officials to insure that local variations to the basic plans were compatible with the overall system.

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### Existing Facilities

NRL. At the onset of this program it was contemplated that Vanguard Control Center and the Vanguard Computing Center would be part of this facility. As soon as the Vanguard Project was transferred to NASA, steps were taken to make available other facilities at the Laboratory to replace those that would no longer be available after consumation of the NASA transfer. This included an interim operation center for data analysis and the utilization of local military communications for data transmission. The IBM computer at the Vanguard Computing Center continues to meet the requirements of the active system on an interim basis.

Dahlgren. As soon as the possible nonavailability of the IBM computing facility became apparent, steps were taken to bring the NORC computer at Dahlgren (Fig. 13) into this program. It was then planned to develop the programming of this computer to meet the requirements of the active detection and tracking system. The NORC computer should be fully programmed to meet these requirements by about 1 July 1959.



Fig. 13 - NORC Computer at U. S. Naval Proving Ground (Dahlgren, Va.)

### Communications

The communications requirements for this program were fairly vague at the beginning primarily because the characteristics of the data were not adequately known. It was

assumed that initially the data must be read at the individual receiver stations and then could be transmitted via regular teletype messages to the operations center at the Laboratory. Since a private-line teletype circuit was in existence from the IGY network between both Fort Stewart and The Vanguard Control Center and Brown Field and the Control Center, additional drops were placed on these lines so that the Stewart line could provide communications for the three eastern stations and the Brown Field line could provide communications for the three western stations. In order to provide the adequate coordination within a Complex, a direct telephone circuit was provided, in the Eastern Complex, so that the Complex manager who is located at the transmitting site can coordinate the activities of his two receiving sites. A feasibility data circuit will be established over this telephone line between Fort Stewart and Silver Lake for the purpose of transmitting analog phase information directly from the Fort Stewart receiver to a Sanborn recorder at Silver Lake. This Sanborn recorder will have corresponding channels of information from the Silver Lake receiver thereby permitting a simultaneous recording on a single recorder of the outputs of both stations. Operation is expected the first week in January. Steps are being taken to install data lines connecting each of the receivers directly with NRL, Washington. These data lines should be in operation by March 15, 1959.

#### CALIBRATION

Each Active Minitrack receiving system is an interferometer designed to measure the angle of arrival of any received radio signal of sufficient strength. Basically, the angle of arrival is determined by measuring the difference of the electrical phase angles of the signal as received by two antennas separated by a fixed distance. In practice, of course, several pairs of receiving antennas must be used to obtain an accurate unambiguous value for the angle of arrival of a signal. Since the receiving system itself affects the phase angles being measured, it must be calibrated so that the phase differences recorded for a given signal can be considered to correspond to the actual angle of arrival of that signal.

For station calibration, it is necessary to have a 108-Mc signal source of known position at least 15,000 feet above the station. For calibration of the Passive Minitrack system, an aircraft has carried a 108-Mc transmitter, and the angle of arrival of a flashing light on the aircraft was measured to an accuracy of two seconds of arc by photographing the light against a star background. The recorded values of the phase differences are then compared with the known angular positions of the aircraft at successive instants of time to determine the proper calibration. This type of station calibration was used initially at Fort Stewart. Since the use of aircraft for calibration is a difficult field operation and under present circumstances only necessary when extreme accuracy is a requirement, the satellite 1958 Beta 2, which has a solar-powered 108.03-Mc transmitter, has been used as a calibration source for the Active Minitrack system. At the time of a predicted 1958 Beta pass, the station tunes to receive the 108.03-Mc signal. The record produced is compared with the post-flight orbit of Beta computed for the calibration pass. The computed positions of Beta are probably accurate to a minute of arc, which is suitable accuracy for calibrating the present Active Minitrack system. The sequence of station calibration is given in Table 1.

Phase differences introduced by drift of the electronics equipment are compensated on the basis of phase measurements made every three hours on a locally generated signal. These internal calibration phase measurements are compared with those made at the time of the station calibration to determine the correction.

Table 1  
Sequence of Station Calibrations

Effective Period	Mode and Date of Calibration	Comments
<u>For Fort Stewart:</u>		
1) 8-5-58 to 9-25-58	Aircraft on 8-10-58	
2) 9-25-58 to 12-21-58	None	Medium baselines modified - previous calibration employed but new ambiguity resolvers made.
3) 12-22-58	58 Beta 2 12-23-58	All baselines shortened to yield better ambiguity resolution.
<u>For Silver Lake</u>		
1) 11-30-58 to 12-23-58	58 Beta 2 on 12-5-58	
2) 12-23-58 to ....	58 Beta 2 on 12-23-58	

Even though the transmission lines from the antennas to the electronics equipment are several hundred feet long, the change in the differences of their electrical lengths is very small over long periods of time. For example, the change for several of the Passive Minitrack stations has not exceeded 0.01 wavelength in a year and a half of operation. Therefore, the effect of the transmission lines can be ignored in making phase reading corrections once the station as a whole has been calibrated.

#### DATA PROCESSING

The emphasis on data processing to date has been on evaluation of system performance and development of techniques of data handling. Known satellites provide the signals for this purpose. These signals are identified by comparison with predicted passes through the antenna beams. Only time and zenith angle correlation were available during the feasibility phase using only the Fort Stewart receiver. After November 30, 1958 when Silver Lake was activated, it became possible to determine height through triangulation using signals received simultaneously at the two stations. This triangulation technique greatly improved the certainty of correlating received signals with predicted satellite passes.

#### Predictions

The following predictions for known satellites are made: the time when each satellite is expected to cross the great circle on which the stations are located within range of a station, the angle (in the plane of the great circle) which the satellite is expected to make

with the local zenith of the receiving station, and the expected height of the satellite above the earth. The predictions are made by interpolation methods applied to predicted orbit positions furnished by the Vanguard Computing Center (Washington, D.C.) in the case of satellites observed by the Passive Minitrack system, and by the Smithsonian Astrophysical Observatory (Cambridge, Massachusetts) for satellites observed optically. These sources supply the height of the satellite and the latitude and longitude of the satellite subpoint for many points of the orbits. Appropriate points are selected from the source data and interpolations made with the aid of graphical devices to determine the height and the position of the subpoint at the time of the beam crossing. From these graphs the zenith angles are determined.

Since August 2, 1958, when the initial Fort Stewart receiving station was first placed in operation in conjunction with the Jordan Lake transmitting station, the known satellites available as possible targets have been those listed in Table 2. Predictions have been

Table 2  
Important Orbital Elements of Satellites for October 2, 1958

1958 Satellite	Popular Name	Nodal Period (min)	Inclination (degrees)	Perigee (statute miles)	Apogee (statute miles)
Alpha	Explorer 1	121.63	33.21	221	1470
Beta 1	Vanguard rocket	Orbital elements are unknown but presumed to be similar to Beta 2			
Beta 2	Vanguard	134.21	34.25	409	2456
Delta 1	Sputnik III rocket	98.71	65.39	135	731
Delta 2	Sputnik III	103.01	65.33	132	990
Epsilon	Explorer IV	148.42	50.28	165	1266
Zeta*	Atlas	101.0	32.29	107	895

\*For December 18, 1958

available for all of these satellites except for Beta 1, for which insufficient optical observations have been made to compute an orbit. Both this target and Beta 2 (which has been tracked continuously by means of its solar-cell-powered Minitrack transmitter) are quite small for observations by reflected energy by the present Active Minitrack installation. Beta 2 has been of exceptional value as a means of calibrating the receiving stations. Its orbit is known to an accuracy of at least one second of time. The predictions for the other satellites may be off from one to twenty minutes in time from the observed positions because of errors in existing source data.

Daily predictions have been made for the known satellites and forwarded to the stations generally one to two days in advance. Predictions were made only for Fort Stewart during the period of August through November and for both Fort Stewart and Silver Lake since November 30, 1958.

## Correlation of Signals with Known Satellites

Tables of reflected signal correlations for August and September were included in the first two progress reports.<sup>1</sup> The additional data correlated since then are included in Appendix B. A summary of the numbers of such correlations is given in Table 3. For reasons discussed below, the correlations in Table 3 and Appendix B are subject to considerable doubt and therefore must be considered tentative.

Table 3  
Summary of Reflected Signal Correlations for Fort Stewart (FS)  
and for Silver Lake (SL)

1958 Satellite	Number of Correlations by Month for 1958				
	August (FS)	September (FS)	October (FS)	November (FS)	December (FS/SL)
Alpha	1	5	1	12	0/7
Delta 1*	11	14	28	35	0/1
Delta 2	8	9	11	12	2/10
Epsilon	0	0	6	22	0/17
Zeta <sup>†</sup>	-	-	-	-	8/20

\*Life ended 3 December 1958

<sup>†</sup>Launched 18 December 1958

For August, September, and October, the Sanborn records made at Fort Stewart were read at NRL to obtain the time and phase information for the satellite passes detected. For November and December the records have been read at the receiving stations and the results reviewed and analyzed at NRL.

As first installed, the spacing of the three 400-foot antennas at Fort Stewart was such that the coarse-to-medium baseline ratio was about 1/9 and the medium-to-fine ratio was about 1/2. Since the coarse baseline had a length slightly greater than a half wavelength, some uncertainty was present in the indicated angular direction of signals near the nominal edge of the antenna beam. When the central antenna of the array was shifted on September 25 to provide a coarse baseline of somewhat less than half wavelength, this increased the difficulty of ambiguity resolution in going from the coarse to the medium baseline, since the baseline ratio was then changed from about 1/9 to about 1/13. The move of one of the antennas in the middle of December changed this coarse-to-medium ratio to about 1/6. The medium-to-fine ratio remained about 1/2 since the fine baseline was cut to about half of its previous length. Even though the improvement in ambiguity resolution resulting from these changes has been very good, current experience indicates that baseline ratios even of 1/5 are marginal on noisy signals. Additional data must be collected to evaluate this item. The Silver Lake station and the Western Complex receiving stations have a medium-to-fine ratio of 1/5.

<sup>1</sup>"Active Minitrack System Initial Progress Report," NRL, p. 6, 11 Sept 1958, and  
"Progress Report No. 2, Active Minitrack System," 16 Oct 1958

In general, because of the difficulty in resolving ambiguities and the lack of suitable station calibration, all of the data collected through December 1958 will be critically reviewed as time permits in the months ahead, and a separate report on these data will be prepared. It is not proposed to spend an undue amount of time on such data since the capability of the whole system is improving very rapidly and data of several months ago are of limited value compared to current data.

The discussion of the 1958 Zeta data demonstrates the importance of obtaining accurate post-flight orbital information to determine how well the Active Minitrack system is performing. It should be noted that all the correlation data presented thus far have made use of predictions (sometimes corrected for errors in time) rather than post-flight information.

During December the number of correlations on satellites has been smaller at Fort Stewart than in previous months because of equipment deterioration and because of station shutdown for a week when one of the 400-foot antennas was moved. The equipment deterioration is largely a result of the rapid temporary installation which was made to get Fort Stewart in operation at the earliest possible date. For example, the transmission line to the antennas was not pressurized and must be replaced.

#### 1958 Zeta

Of particular interest during the month of December have been the observations made of the satellite 1958 Zeta which went into orbit on December 18 at 2306 UT. In addition to being a sufficiently large target to give good reflected signals, it contained an active transmitter until well after the end of the year. The transmitted signal gave an almost positive means of identifying the reflected signals received from an object as being those from 1958 Zeta. At Fort Stewart the signal level from a Collins R390 receiver tuned to 107.97 Mc was recorded along with the other signal levels and the phase recordings. This recording was quite helpful in identifying signals received on several passes. Occasionally, Silver Lake actually tuned the station so that it would listen to the satellite's transmitter to obtain a signal for phase measurement. This provided information on a few passes which might otherwise have been missed, but it did eliminate the possibility of recording a reflected signal from that pass.

The period of the satellite was such that each day at least one pass would be in a favorable angular position from each station. However when apogee moved around close to the stations the range became too great for good signals to be received. Identifiable signals were received from 22 passes during the thirteen days after launch with coincident signals being received at both stations on five passes. In a few cases, although the signals were identifiable as those from 1958 Zeta, there was insufficient phase information to obtain an unambiguous solution. Since the Fort Stewart station was out of operation from December 17 through 21 for changing the location of the antenna, no triangulation was possible on the first four days of 1958 Zeta.

The first signal from 1958 Zeta was received at Silver Lake on December 19, 190938 UT. A quite readable record, as shown in Fig. 14, was obtained from this pass on all channels except the EW 57.2928 wavelength baseline which receives a polarization at right angles to that of the other antennas. There was also no signal-level change recorded for this pass on the EW 57.2928 wavelength baseline and only a slight one recorded for the NS 43.9216 wavelength baseline. However when the second pass came by, a readable signal was obtained on only the EW 57.2928 baseline as is seen in Fig. 15. The EW 57.2928 baseline has the same polarization as the transmitter, while the other channels at Silver Lake are cross-polarized.

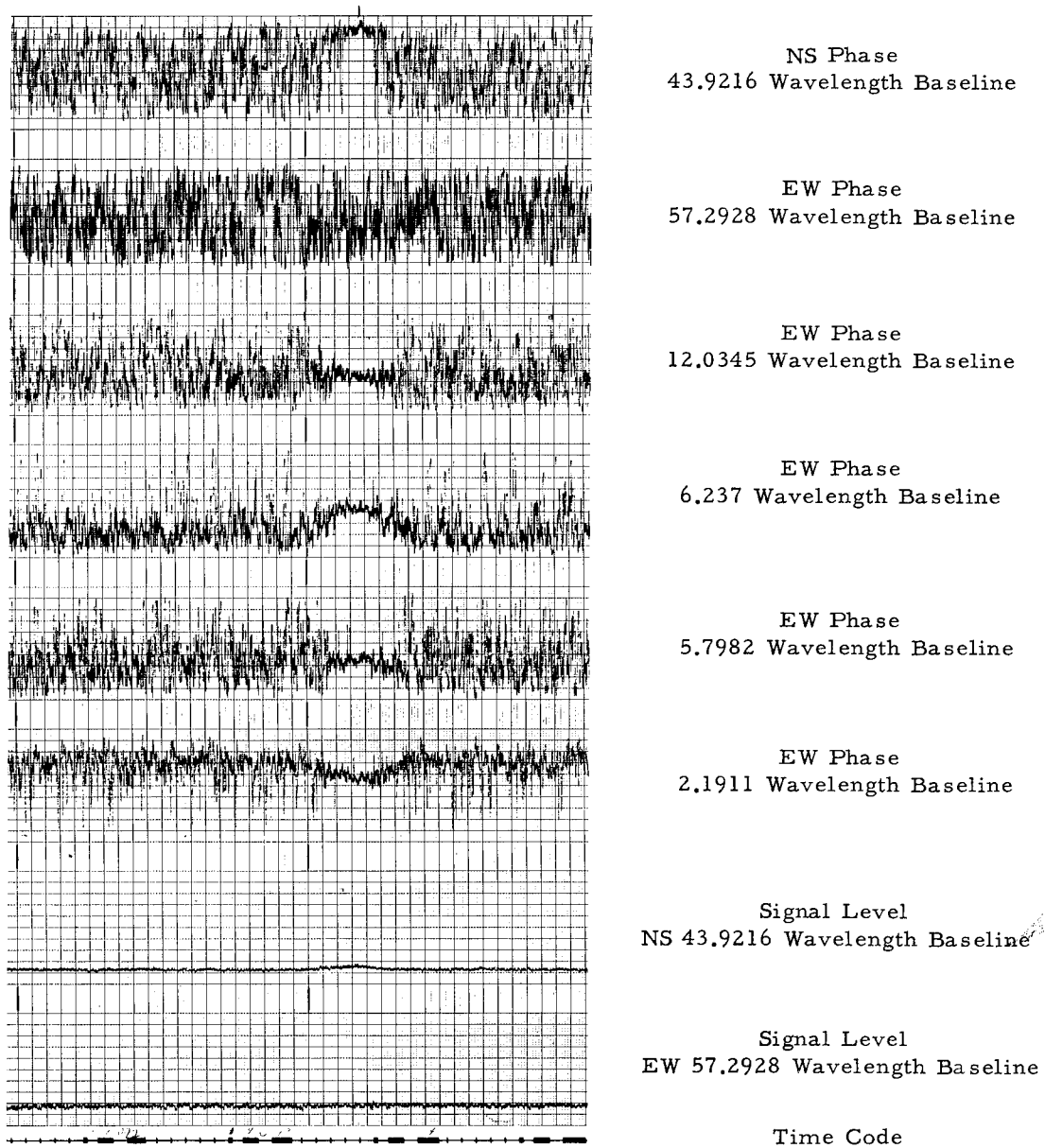
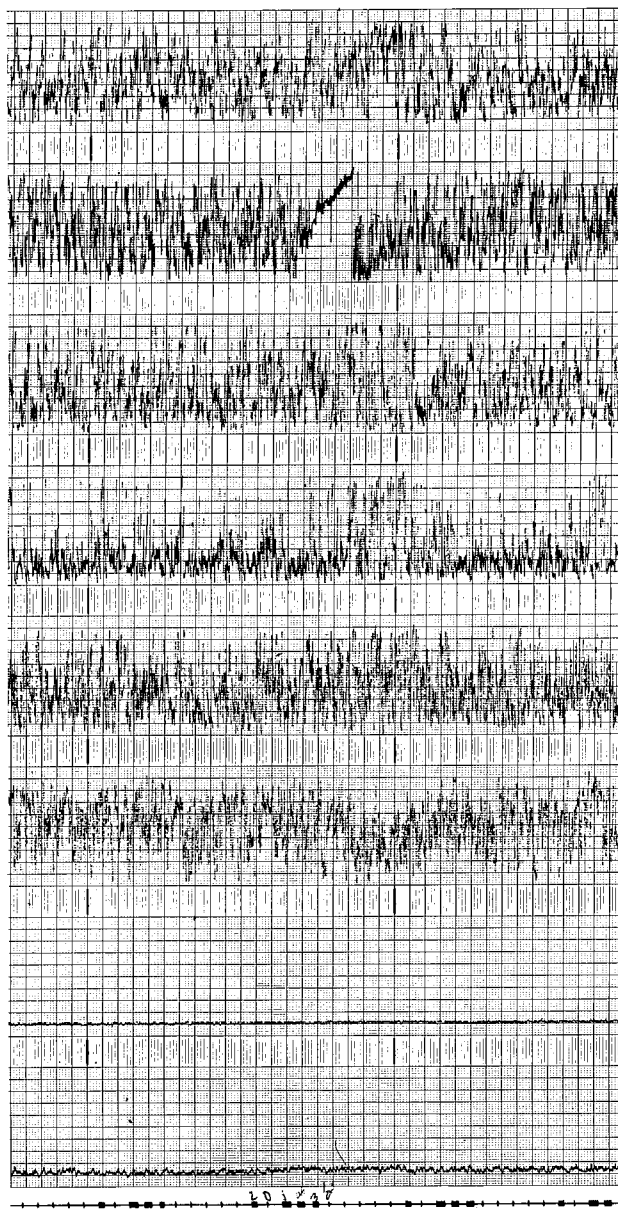


Fig. 14 - Silver Lake record of 1958 Zeta pass at 190938 UT  
on December 19 at a height of 295 miles



NS Phase  
43.9216 Wavelength Baseline

EW Phase  
57.2928 Wavelength Baseline

EW Phase  
12.0345 Wavelength Baseline

EW Phase  
6.237 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

EW Phase  
2.1911 Wavelength Baseline

Signal Level  
NS 43.9216 Wavelength Baseline

Signal Level  
EW 57.2928 Wavelength Baseline

Time Code

Fig. 15 - Silver Lake record of 1958 Zeta pass at 205433 UT  
on December 19 at a height of 228 miles

A very strong signal received at Silver Lake on December 20 at 202838 UT is shown in Fig. 16. At this time the satellite was at about 250 miles height and at a very favorable angular position with respect to both the station and the transmitter. The first good coincident pair of signals was received at both stations on December 22 at 192640 UT and recordings of these are shown in Figs. 17a and 17b. The Fort Stewart record shows very clearly the signal from the R390 receiver tuned to Zeta's frequency. The pass of December 22 at 210807 UT at Silver Lake (Fig. 18) gives a good indication of the signal received from a range of about 1000 statute miles even though the observation was near the horizon. Other records of signals are shown in Appendix C. It will be noted that the signals of longer duration all have a similar pattern especially in the EW 57.2928 channel at Silver Lake. The very short signals naturally cannot exhibit such a pattern of crossovers.

The complete set of observations from Silver Lake are tabulated in Table 4 giving pertinent information on the observations and also the predicted position of the satellite. Actually the "predicted" columns contain some information from post-flight computations as there were no predictions made for the stations for the first few days. Post-flight data have been computed only for the early passes and the ones where coincident observations were made. A complete set of observations from Fort Stewart is shown in Table 5 which also gives some prediction data and some post-flight data. It will be noted that sometimes the predictions and post-flight data differ by several minutes. This made the plot of Fig. 19 quite helpful in determining the proper observational signal. This chart exhibits a stroboscopic effect in that the station is looking at a pass at intervals of approximately one day. In such a plot the change of period for a satellite which has practically no decay of period is a straight line. It will be noted that the plots for 1958 Zeta are all curves with ever-increasing slope.

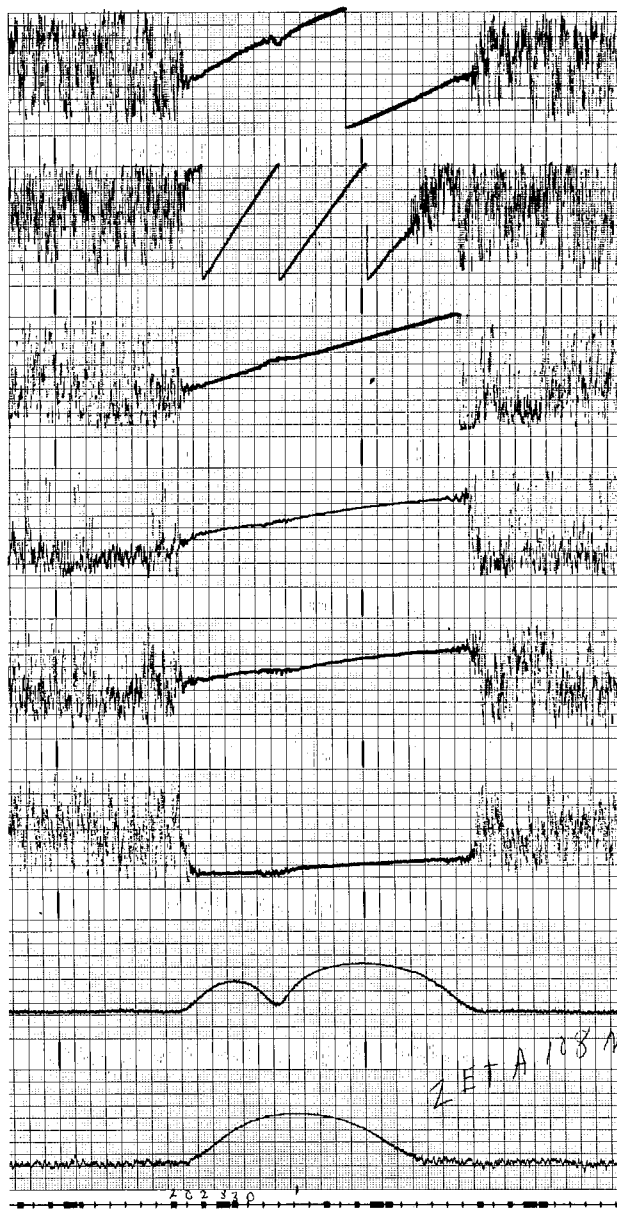
The coincident pairs of signals are tabulated in Table 6 along with both prediction and post-flight data. This table of data will show very clearly the difference between predicted and post-flight data. It also points up the fact that the plot of Fig. 19 frequently gives a better time to look for a pass than does the prediction information.

The method of making predictions is described earlier in the report. The post-flight data are computed by the Vanguard Computing Center from improved post-flight orbital elements. These computations provide range in kilometers, azimuth in degrees, and elevation angle in degrees at a specified time. For the tables the range was converted to statute miles and a height computed in statute miles by an analog device. This device represents a great circle plane through the stations on which the elevation angles from each station are set with markers. The height above the earth can thus be read off directly where the two markers intersect.

### Signal Analysis

The Sanborn recordings made at Fort Stewart and at Silver Lake are being studied to attempt to establish suitable criteria for distinguishing between satellites and other objects or interfering signals. The various sources for providing a signal response in the Active Minitrack system can be listed as follows:

- (1) Reflections from
  - (a) Meteorites
  - (b) Satellites (artificial or natural)
  - (c) Aircraft



NS Phase  
43.9216 Wavelength Baseline

EW Phase  
57.2928 Wavelength Baseline

EW Phase  
12.0345 Wavelength Baseline

EW Phase  
6.237 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

EW Phase  
2.1911 Wavelength Baseline

Signal Level  
NS 43.9216 Wavelength Baseline

Signal Level  
EW 57.2928 Wavelength Baseline

Time Code

Fig. 16 - Silver Lake record of 1958 Zeta pass at 202838 UT  
on December 20 at a height of 253 miles



NS Phase  
43.9216 Wavelength Baseline

EW Phase  
57.2928 Wavelength Baseline

EW Phase  
12.0345 Wavelength Baseline

EW Phase  
6.237 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

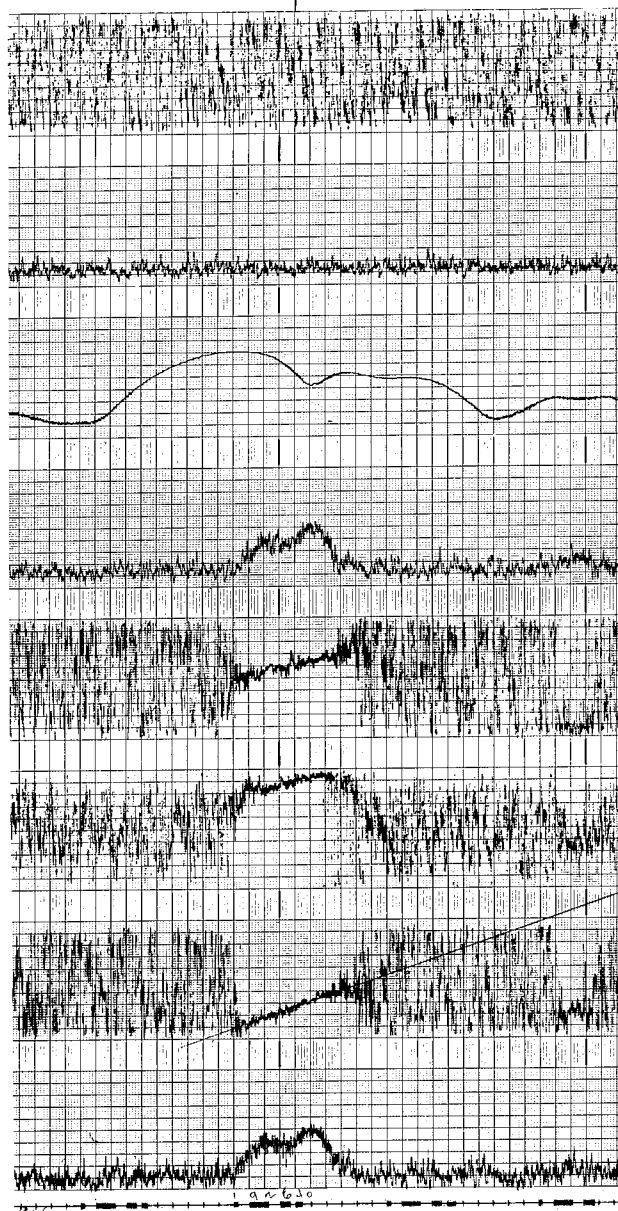
EW Phase  
2.1911 Wavelength Baseline

Signal Level  
NS 43.9216 Wavelength Baseline

Signal Level  
EW 57.2928 Wavelength Baseline

Time Code

Fig. 17a - Silver Lake record of 1958 Zeta pass at 192640 UT  
on December 22 at a height of 365 miles



Yagi Phase

Signal Level,  
Yagi

Signal Level, Noise  
Correlation Channel,  
107.97 Mc

Signal Level,  
2.6795 Wavelength Baseline

EW Phase  
2.6795 Wavelength Baseline

EW Phase  
3.1187 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

Signal Level  
5.7982 Wavelength Baseline

Time Code

Fig. 17b - Fort Stewart record of 1958 Zeta pass at 192640 UT  
on December 22 at a height of 365 miles

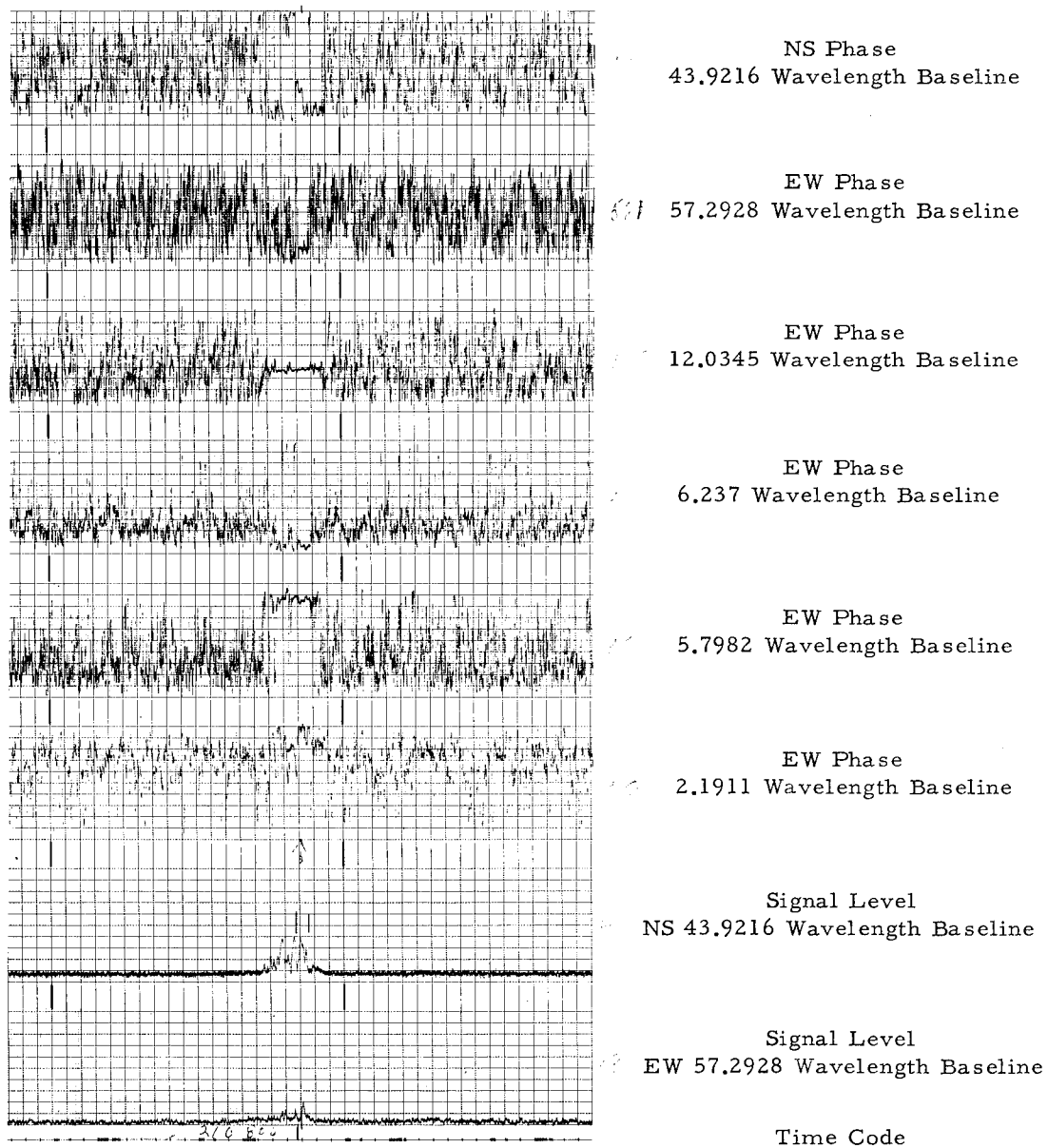


Fig. 18 - Silver Lake record of 1958 Zeta pass at 210807 UT  
on December 22 at a height of 349 miles

Table 4  
Reflected Signal Correlations for Silver Lake for December 1958  
Satellite 1958 Zeta

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Dec 19	190939	190939*	90 E	85 E*	5.5	295*
19	205433	205433*	†	70 E*	3.2	228*
19	223837	223837*	81 W	83 W*	0.5	167*
20	202838	202838*	61 E	57 E*	19.0	253*
21	181130	181130*	39 E	38 E*	1.2	465*
21	195920	195920*	54 E	53 E*	4.2	317*
22	174131	174150	73 E	69 E	0.3	449
22	192640	192640*	49 E	51 E*	9.5	365*
22	210807	210807*	77 W	75 W*	4.4	349*
23	170640	170540	69 E	65 E	3.2	606
23	185046	185046*	48 E	51 E*	14.0	405*
24	181114	181114*	45 E	46 E*	11.0	460*
25	172824	172824*	47 E	47 E*	8.5	540*
26	164206	164340	†	2 E	5.5	670
27	155236	155455	53 E	51 E	0.5	732
28	145926	150255	56 E	56 E	2.0	797
28	164324	164324*	†	33 E*	12.0	755*
29	154611	154611	40 E	32 E	10.4	787
30	144847	144715	†	44 E	0.6	803
30	163239	163239*	62 E	54 E*	3.2	723*

\* Post-flight information

† Insufficient phase data

Table 5  
Reflected Signal Correlations for Fort Stewart for December 1958  
Satellite 1958 Zeta

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Dec 22	192640	192640*	29 W	28 W*	7.0	365*
23	185046	185046*	22 W	20 W*	9.0	405*
24	181114	181114*	20 W	18 W*	12.0	460*
25	172824	172824*	9 W	9 W*	3.0	540*
27	173753	173718	21 W	17 W	4.4	732
28	164324	164324*	14 W	19 W*	13.0	755*
29	154611	154611*	29 W	15 W*	12.0	787*
31	152611	152745	14 W	18 W	12.0	787

\* Post-flight information

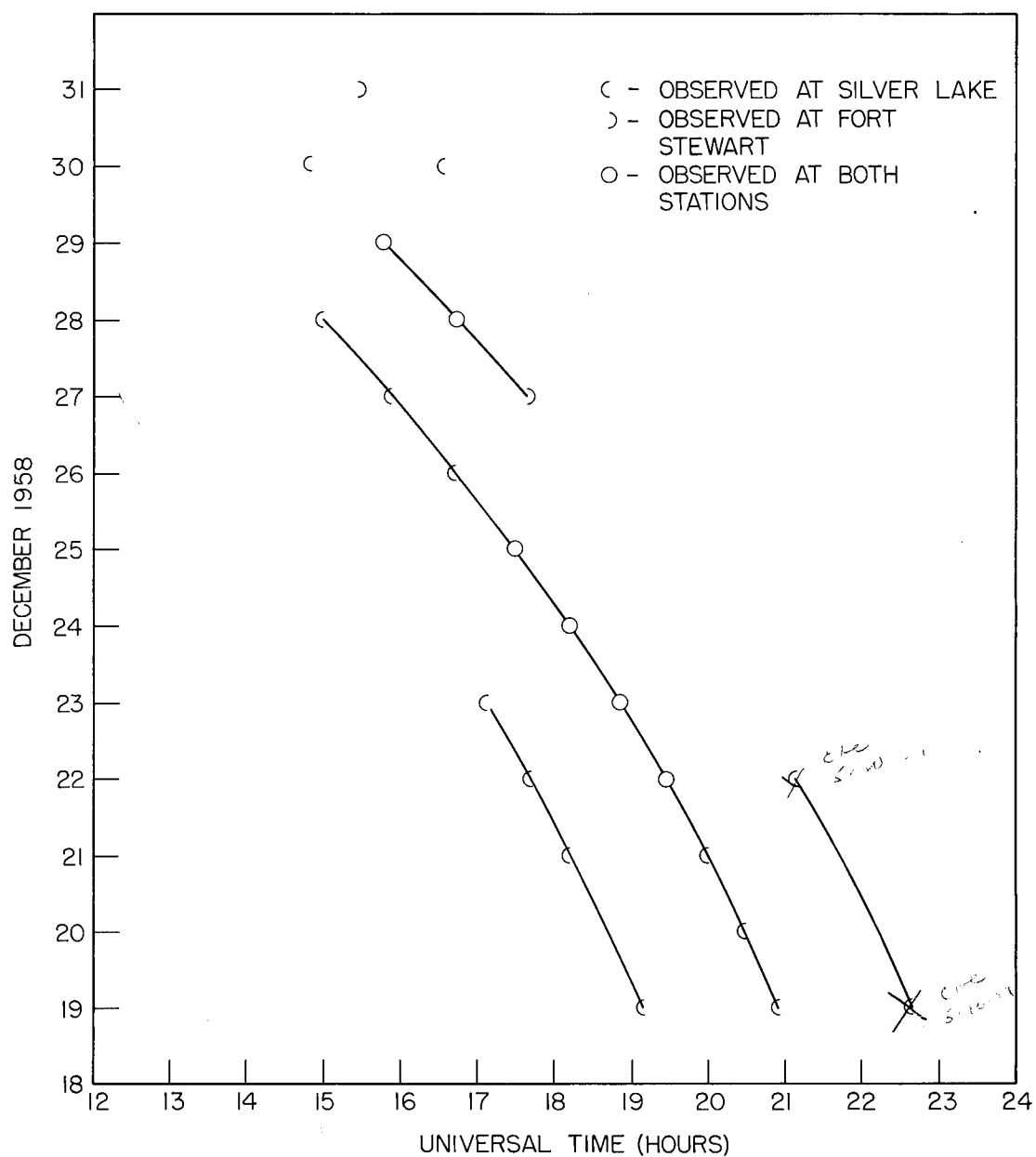


Fig. 19 - Passes of the satellite 1958 Zeta intercepted by the Eastern Complex in December 1958

Table 6  
Reflected Signal Triangulation for the Eastern Complex for December 1958  
Satellite 1958 Zeta

Date (1958)	Source	Universal Time (hr-min-sec)	Silver Lake		Fort Stewart		Triangulation Height (statute miles)
			Zenith Angle (Deg)	Range (statute miles)	Zenith Angle (Deg)	Range (statute miles)	
Dec 22	P*	192400	53.5 E	550	25.7 W	385	345
22	O*	192640	49.0 E	545	28.9 W	415	370
22	PF*	192640	50.5 E	545	27.8 W	411	365
	O-PF*	0	-1.5	0	1.1	4	5
23	P	185000	46.0 E	565	27.0 W	455	425
23	O	185046	47.8 E	605	21.6 W	455	425
23	PF	185046	50.5 E	607	20.1 W	437	405
	O-PF	0	-2.7	-2	1.5	18	20
24	P	181033	43.0 E	700	16.0 W	555	527
24	O	181114	45.2 E	640	20.0 W	495	470
24	PF	181114	46.3 E	661	17.5 W	504	460
	O-PF	0	-1.1	-21	2.5	-9	10
25	P	172915	44.0 E	770	10.0 W	585	583
25	O	172824	46.7 E	760	9.0 W	555	540
25	PF	172824	46.8 E	760	8.8 W	559	540
	O-PF	0	-0.1	0	0.2	-5	0
28	P	164710	33.0 E	930	11.0 W	828	707
28	O	164324	†	---	14.0 W	---	---
28	PF	164324	33.2 E	783	18.9 W	705	755
	O-PF	0	-----	---	4.9	---	---

\*P - Predicted information

O - Observed information

PF - Post-flight information

O-PF - Error of observation compared with post-flight information

† Insufficient phase data

## (2) Transmission from

- Sun and radio stars
- Atmospherics
- Man-made interference
- Own transmitter (direct or scatter)
- Other radio transmitters (splash-over, image frequency, etc.)

The broad-band noise sources (2a, b, and c above) are identified by the use of receiver tuned slightly off the transmitter frequency. At the Fort Stewart station a Collins R390 receiver is connected to the 11.7-Mc output of one antenna preamplifier and usually tuned to respond to 108.03 Mc. Any system response which correlates with the output of this receiver is considered to be from a broad-band noise source, except in the case of 1958 Beta 2 and Epsilon passes where the transmissions on 108.03 Mc have been used to gain additional antenna pattern information. Interference from other transmissions is checked

with an audio monitor and by the character of the signal recorded. Scatter or direct feed from the transmitter would show as a more or less steady AGC indication. The presence of this type of signal could be checked by turning the transmitter off and on. To date this has not been a problem; however it may be encountered under certain weather conditions.

In some cases, aircraft reflections are readily discernible from the strong signal produced and the very low phase rate present. Correlation with known aircraft movements would be helpful but does not appear feasible because of the long delays involved in obtaining the movement information. Audio spectrographic equipment is being developed to separate the very low doppler offset frequencies to be expected from aircraft, but this equipment will not be available for test until early 1959.

Signal returns have been received from the natural moon when it is in the antenna beam. Programmed turn-off of the transmitter was used to prove that these signals were from the transmitter. Moreover, when the moon moves out of the beam these signals are no longer received.

Because of the large number of signals received at the stations, the identification of any single response as an unknown satellite is impossible at this time. However, whenever both stations of either complex indicate the simultaneous occurrence of an event, the probability of determining the presence of an unknown orbiting object is greatly increased if the signals received result in a triangulation which gives a reasonable height. In general, satellites will be above 100 statute miles and meteorites will occur at lower heights. Table 7 shows the number of signals of a given time duration for which a phase reading could be made, as read from the Sanborn record for Silver Lake for December 6, 1958. In addition to the signals indicated in the table, an additional 100 signals occurred, most of which had a duration less than 0.3 second, but for which no phase readings could be made.

Table 7

Signal Duration (sec)	Cumulative Number of Signals*	Cumulative Percentage
0.1	22	10.2
0.2	73	34.0
0.3	111	51.6
0.4	162	75.3
0.5	172	80.0
0.6	196	91.1
0.7	200	93.0
0.8	205	95.0
0.9	205	95.0
1.0	209	97.2
>1.0	215	100.0

\*Number of signals having stated duration or less

The signals received fall into the following three general categories:

1. Short spikes having a duration of 0.3 second or less. Such signal durations correspond approximately to the average time meteorites would be expected to remain in the beam since meteorites are assumed to be at a height of from 50 to 75 miles and have speeds of about 25 miles per second.
2. Signals from 0.3 to 3 seconds duration which have readable phase information. Satellite signals generally have this duration but may be shorter or longer.
3. Signals having a duration greater than 3 seconds. Most interference signals are in this category.

Analysis of the reflected signal correlations indicates that the Silver Lake system in its present form has a range of about 1000 statute miles for objects the size of 1958 Delta 1 and 1958 Zeta. Exact range correlation is not possible because the exact effective sizes of the various satellites as reflectors is not known. Calculated effective echoing areas has yielded results considerably in excess of what might be expected from estimated physical sizes of the satellites. Additionally the echoing area appears to be a function of the angle formed at the satellite by the lines of sight to the transmitting and receiving sites. These results will be further examined using improved data becoming available.

#### Orbit Computations

The mathematical formulation for the orbit computations to be performed from the Active Minitrack data is being developed by the U. S. Naval Observatory and the University of Cincinnati Observatory (under Navy contract). This work was undertaken in December and will be programmed for the NORC computer. Advantage is being taken of the experience gained in the development of the orbit computation programs for the IBM 704 at the Vanguard Computing Center. The programmers at the U.S. Naval Proving Ground have been briefed on the basic numerical integration scheme to be used as well as on the Fourier series operations basic to the general oblateness perturbation method of orbit calculation.

The NORC is particularly well suited to performing orbit computations because of its combination of high speed and high precision. It has a multiplication time of 31 microseconds and can perform 15,000 complete operations per second. It is a three-address decimal machine with a word length of 13 decimal digits.

#### OPERATIONS

##### Concept

In establishing the procedures for operating the Space Surveillance System it is recognized that such an intelligence system involves various degrees of military security. The existence of the stations themselves cannot be obscured nor the purpose of the stations hidden. Surveillance itself is a continuous and routine operation. The operation of all stations should be so routinized that the existence of various stages of system alerts will be confined to the Operations Center but will go unnoticed at the individual stations.

The functioning of each station during its day-to-day operation must not vary regardless of what level of interest or alertness may exist at the Operations Center in Washington. This situation is achievable by transmitting data from each receiver in real time to the Operations Center. The stations themselves will be responsible to observe the output of the individual receivers for proper functioning of the equipment. The data itself will not become meaningful until it is brought together in the Operations Center after appropriate analysis.

#### Station Manning

During the experimental phases it was determined that a contract-type operation would serve the needs of the program best. In view of the urgency to bring the system into operation, a modification to the procurement contract was negotiated with the Bendix Corp., the manufacturer of the receiver equipment, to man and operate all six stations, including the transmitting stations. This function has been separated from equipment function and is now covered by separate contract. Organizationally, the Bendix Corp. has placed a manager in charge of the Eastern Complex at Jordan Lake and a manager in charge of the Western Complex at Gila River. Under these two Complex managers are the station managers for each station. The crew at each station consists of the manager, a technical advisor, four field engineers, four technicians, a typist, and a handy man. This crew is supplemented by a few additional individuals whenever necessary owing to local conditions.

APPENDIX A  
Space Surveillance Stations  
(SPASUR)  
Detailed Data

Table A1  
Fort Stewart Receiving Station

- |   |  |                      |
|---|--|----------------------|
| 1. <u>Name:</u>                               | Fort Stewart   |                      |
| 2. <u>Location:</u>                           | <u>SPASUR Site</u>   | <u>VANGUARD Site</u> |
|   | Lat. 31° 58' 36"N  | 31° 59' 07"N         |
|   | Long. 81° 30' 34"W   | 81° 29' 42"W         |
| 3. <u>Azimuth to Transmitter (from south)</u> | 100° -47' -51"   | 100° -39' -20"       |
| 4. <u>Address:</u>                            | U.S. Navy Fort Stewart Space Surveillance Station, Fort Stewart, Georgia   |                      |
| 5. <u>Telephone:</u>                          | Hinesville, Georgia TR-6-3571  |                      |
| 6. <u>Communication Facilities:</u>           |  |                      |
|   | a. Private telephone: Fort Stewart - Jordan Lake - Silver Lake (temporarily being utilized as a R and D data circuit line) |                      |
|   | b. Private teletype: Fort Stewart - Vanguard Control Center - Jordan Lake - Silver Lake                                    |                      |
|   | c. Data line: Fort Stewart - NRL (Planned)   |                      |
| 7. <u>Power Facilities:</u>                   |  |                      |
|   | a. Vanguard Site -   |                      |
|   | (1) Primary - One 40-kw diesel generator   |                      |
|   | (2) Two Standby - Each 40-kw diesel generator  |                      |
|   | b. SPASUR Site   |                      |
|   | (1) Primary - Commercial power from Georgia Power and Light Co. 120/208 3-phase, 60-cycle, 150 kw. (Planned)               |                      |
|   | (2) Standby - One 100-kw diesel generator.   |                      |
| 8. <u>Real Estate Rights:</u>                 |  |                      |
|   | a. Type - government property with tenancy rights for SPASUR station.  |                      |
|   | b. Acreage - 502.66 acres.   |                      |
|   | c. Cost - None.  |                      |

Table A2  
Jordan Lake Transmitting Station

1. Name: Jordan Lake
2. Location:

<u>Feasibility Site</u>	<u>Initial Capability Site</u>
Lat. 32° 39' 17" N	Lat. 32° 39' 17" N
Long. 86° 15' 53" W	Long. 86° 15' 51" W
3. Azimuth:
  - a. To Fort Stewart (SPASUR Site)  
278° -15' -16"
  - b. To Silver Lake Site  
98° -15' -15"
4. Address: U.S. Navy Jordan Lake Space Surveillance Station, Box 158,  
Wetumpka, Alabama
5. Telephone: Wetumpka 7541
6. Communication Facilities:
  - a. Private Telephone: Fort Stewart - Jordan Lake - Silver Lake (temporarily being utilized as a R and D data circuit line)
  - b. Private Teletype: Fort Stewart - Vanguard Control Center - Jordan Lake - Silver Lake
7. Power Facilities:
  - a. Primary - Commercial power from Alabama Power Company 440/220/110 3-phase, 60-cycle, 250-kw
  - b. Standby - None
8. Real Estate Rights:
  - a. Type - Private Property owned by Mr. J. A. Knight and Mr. and Mrs. Jake Brisker, leased by the 6th Naval District for the government for a one year period starting on Sep. 30, 1958 with an option by the government to renew the lease for four additional one-year periods.
  - b. Acreage - Mr. Knight - 29.3 acres.  
Mr. and Mrs. Brisker - 28.8 acres.
  - c. Annual Cost - \$938.

Table A3  
Silver Lake Receiving Station

1. Name: Silver Lake
2. Location: Lat.  $33^{\circ} 8' 54''$  N  
Long.  $91^{\circ} 01' 16''$  W
3. Azimuth to Jordan Lake  
 $275^{\circ} 40' 11''$
4. Address: U.S. Navy Silver Lake Space Surveillance Station, Hollandale, Mississippi
5. Telephone: Greenville 2-1072
6. Communication Facilities:
  - a. Private telephone: Fort Stewart - Jordan Lake - Silver Lake (temporarily being utilized as a R and D data circuit line)
  - b. Private Teletype: Vanguard Control Center - Fort Stewart - Jordan Lake - Silver Lake
  - c. Data Line: Silver Lake - NRL (Planned)
7. Power Facilities:
  - a. Primary - Commercial power from Twin County Electric Power Assoc. of Hollandale, Miss. 220/110 3-phase, 60-cycle, 44-kw
  - b. Standby - None.
8. Real Estate Rights:
  - a. Type - Private land on the Silver Lake Plantation owned by the Silver Lake Plantation Co. The 6th Naval District has negotiated a one-year lease starting on Sep. 30, 1958 for a one-year period with the option to renew for four additional one-year periods.
  - b. Acreage: 71.58 acres.
  - c. Annual Cost: \$1430.04.

Table A4  
Elephant Butte Receiving Station

1. Name: Elephant Butte
2. Location: Lat.  $33^{\circ}26'35''N$   
Long.  $106^{\circ}59'50''W$
3. Azimuth to Transmitter (Gila River)  
 $86^{\circ}51'35''$
4. Address: U.S. Navy Elephant Butte Space Surveillance Station, Box 111,  
Truth or Consequences, New Mexico
5. Telephone: Truth or Consequences 630
6. Communication Facilities:
  - a. Private Telephone: Elephant Butte - Gila River - Brown Field
  - b. Private Teletype: Vanguard Control Center - Elephant Butte - Gila River - Brown Field
  - c. Data Line: Elephant Butte to NRL (planned)
7. Power Facilities:
  - a. Primary - Rural Electric Administration 220/110 3-phase, 60-cycle, 100-kw
  - b. Standby - 100-kw diesel generator
8. Real Estate Rights:
  - a. Type - Private property owned by the Victoria Land and Cattle Co. The 8th Naval District has negotiated a one-year lease starting on August 1, 1958 with the option to renew for four additional one-year periods.
  - b. Acreage: 137.74 acres
  - c. Annual Cost: \$100.

Table A5  
Gila River Transmitting Station

1. Name: Gila River
2. Location: Lat.  $33^{\circ}06'31''$ N  
Long.  $112^{\circ}01'46''$ W
3. Azimuth:
  - a. To Elephant Butte:  
 $264^{\circ}05'51''$
  - b. To Brown Field:  
 $84^{\circ}05'51''$
4. Address: U.S. Navy Gila River Space Surveillance Station, Gila River (Phoenix), Arizona
5. Telephone: Maricopa: LO 8-2226
6. Communication Facilities:
  - a. Private Telephone: Elephant Butte - Gila River - Brown Field
  - b. Private Teletype: Vanguard Control Center - Elephant Butte - Gila River - Brown Field
7. Power Facilities:
  - a. Primary - Arizona Public Service Co. 440/220/110 3-phase, 60-cycle, 250-kw
  - b. Standby - None
8. Real Estate Rights:
  - a. Type - The land is part of Maricopa-Pima Indian reservation and is deeded in trust by the U.S. government to the Pima Indian tribe. A right-of-way was negotiated by the 11th Naval District with the Indian tribe to permit the construction and, with all other necessary rights, to operate this station. This right-of-way was obtained for a period of one year starting on Aug. 12, 1958 with an option for the government to renew the right-of-way for four additional one-year periods.
  - b. Acreage: 81.3 acres
  - c. Annual Cost: \$2033.

Table A6  
Brown Field Receiving Station

1. Name: Brown Field
2. Location: Lat. 32° 34' 42"N  
Long. 116° 58' 07"W
3. Azimuth to Transmitter:  
261° 25' 01"
4. Address: U.S. Navy Brown Field Space Surveillance Station, Brown Field  
(San Diego), California
5. Telephone: Chula Vista: Garfield 2-6787
6. Communication Facilities:
  - a. Private Telephone: Elephant Butte - Gila River - Brown Field
  - b. Private Teletype: Vanguard Control Center - Elephant Butte - Gila River - Brown Field
  - c. Data Line: Brown Field to NRL (planned)
7. Power Facilities:
  - a. Vanguard Site
    - (1) Primary - Commercial Power from the California Power and Light Co. - 220/110 3-phase, 60-cycle
    - (2) Standby - None
  - b. SPASUR Site
    - (1) Primary - California Power and Light Co. - 220/110, 3-phase, 60-cycle
    - (2) Standby - None
8. Real Estate Rights:
  - a. Type - Part of the station is government land belonging to Brown Field. The remaining land belongs to Mr. Slegher Brink, Jr. The 11th Naval District negotiated a one-year lease starting on Aug. 1, 1958 with an option to renew the lease for four additional one-year periods.
  - b. Acreage:
    - (1) Brown Field: Approx. 60 acres
    - (2) Private land: 100 acres
  - c. Annual Cost: \$5000.

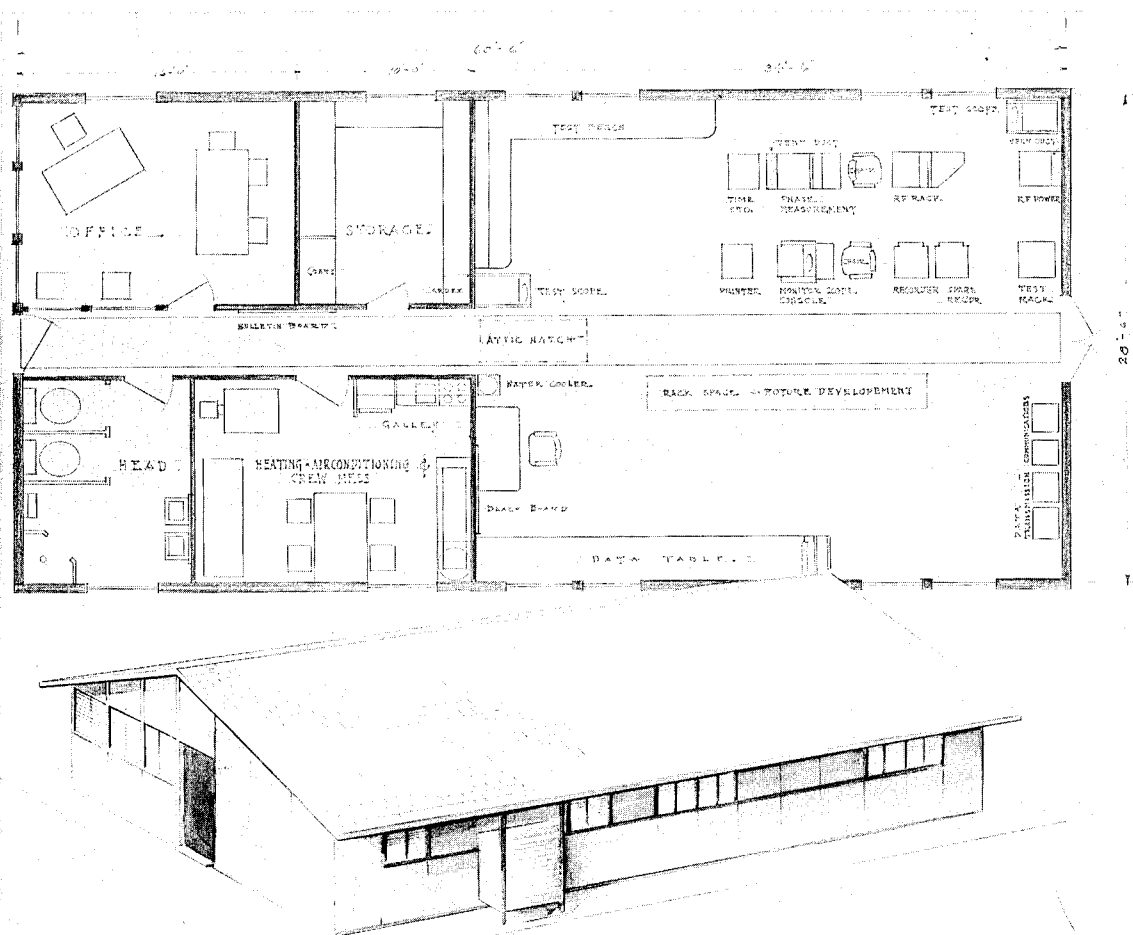


Fig. A1 - Building type used at receiving stations

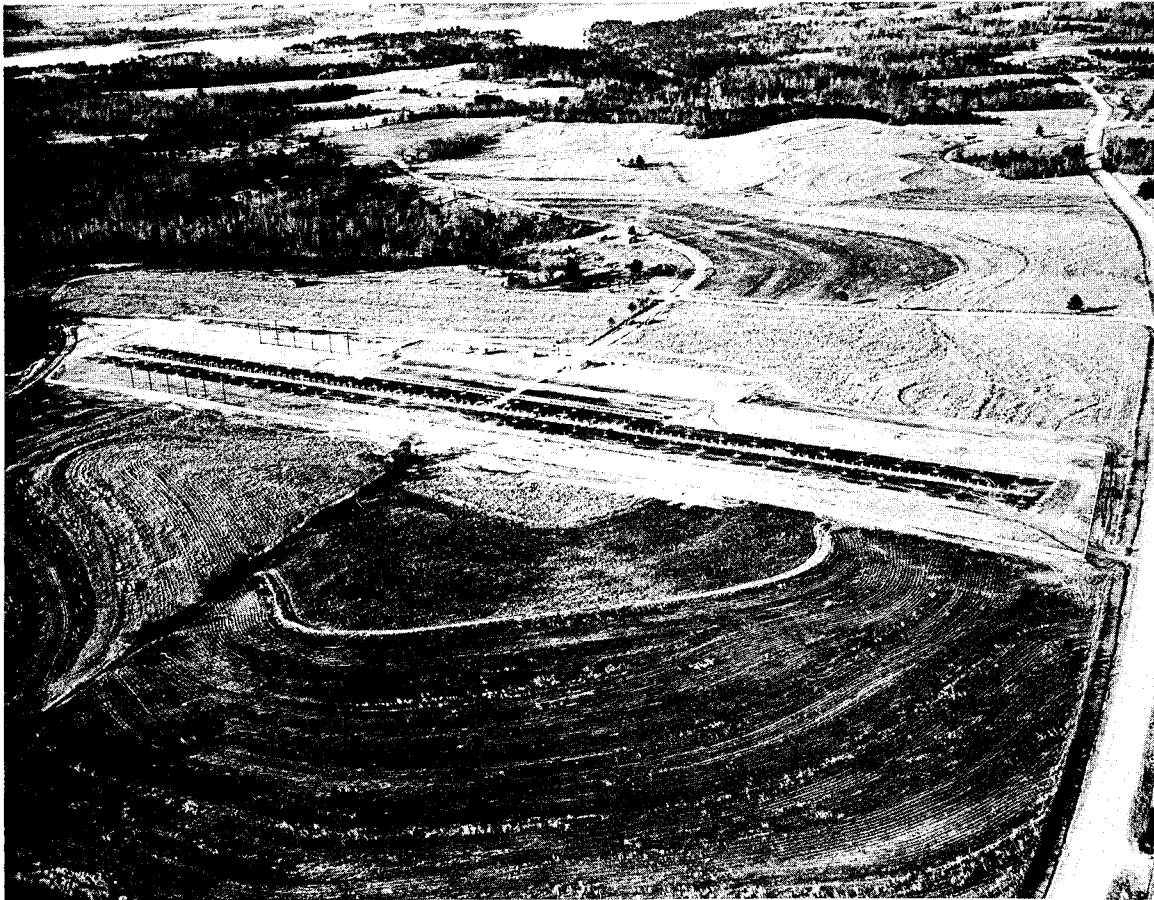


Fig.A2 - Jordan Lake transmitting site showing the new 1600-foot antenna posts and the old 400-foot antenna array

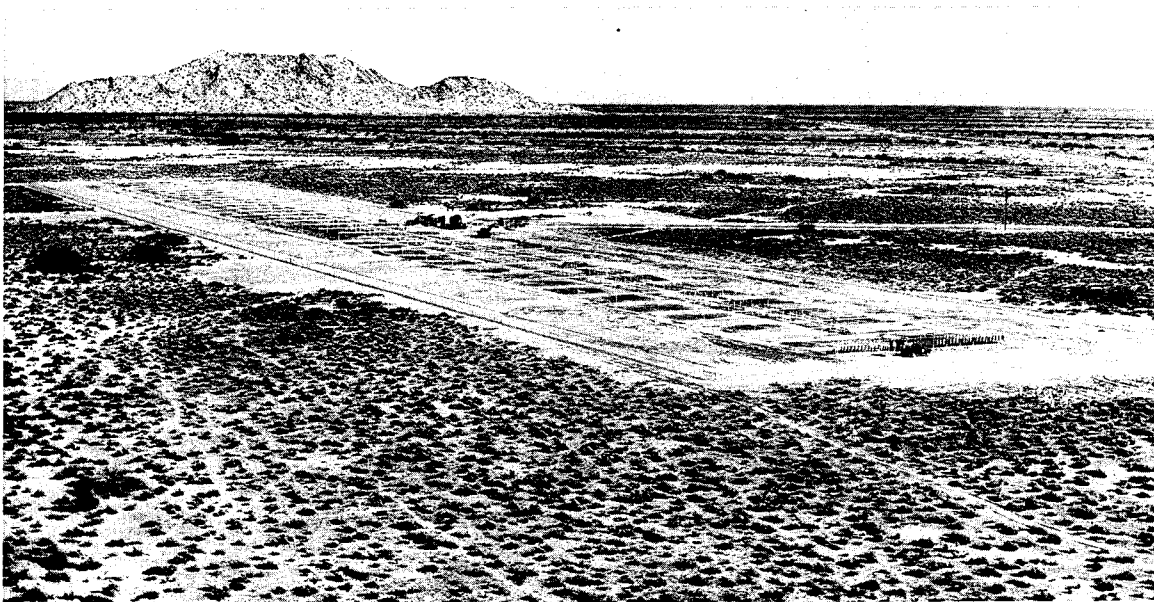


Fig. A3 - Gila River transmitting site before installation of the 1600-foot antenna

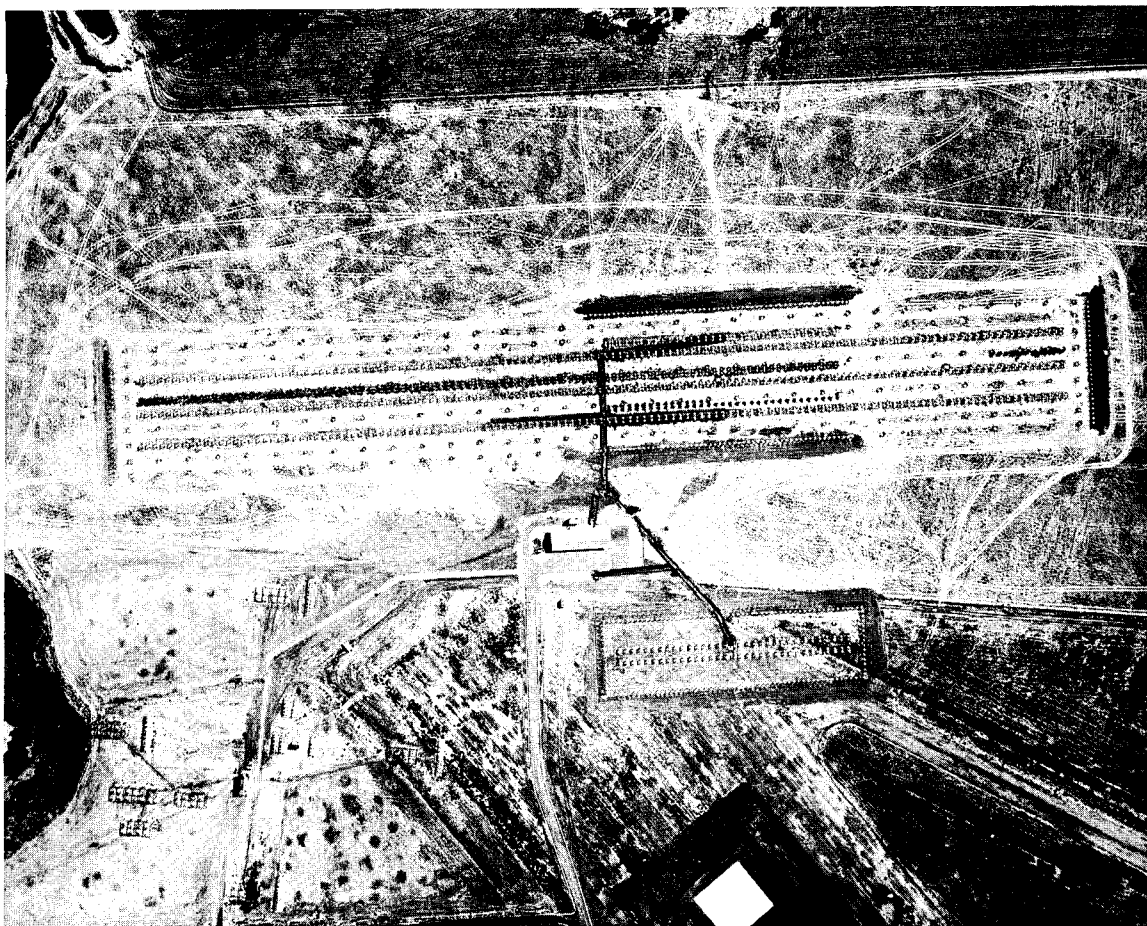
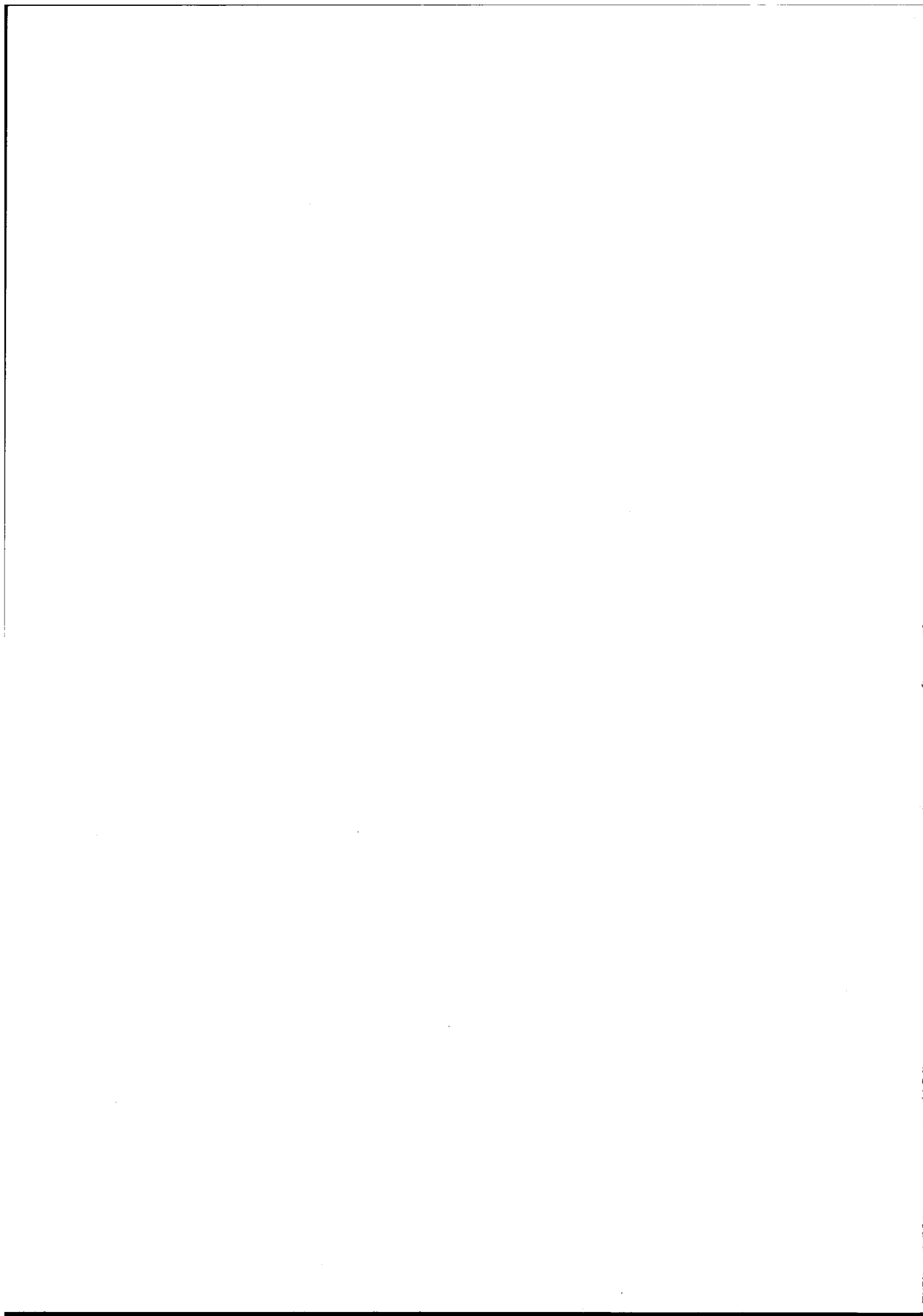


Fig. A4 - Brown Field receiving site showing posts for four 1600-foot antennas and one 400-foot antenna in the main array and the 400-foot fine-baseline array



**APPENDIX B**

**Tables of Correlations of Reflected Signals  
with Predicted Passes of Known Satellites**

Table B1

Reflected Signal Correlations for Fort Stewart, Satellite 1958 Alpha

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Oct 30	005812	005900	37 W	25 W	5.0	232
Nov 2	000638	000700	51 W	39 W	2.0	223
3	225300	225400	5 W	15 E	1.5	235
4	004509	004900	67 W	70 W	0.5	245
4	231358	231300	56 W	48 W	1.4	224
6	220341	220300	23 W	4 W	0.4	260
6	235120	235800	76 W	70 W	0.3	229
7	221746	222036	48 W	46 W	0.4	318
8	224223	223918	83 W	64 W	0.4	332
14	203905	204300	64 W	47 W	0.1	638
15	191144	190548	12 W	14 W	0.4	742
17	174949	174733	35 E	8 E	0.1	932
18	200233	200500	13 W	38 W	0.1	726

Table B2

Reflected Signal Correlations for Silver Lake, Satellite 1958 Alpha

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Dec 19	072500	072500	8 W	26 E	9.0	359
20	073900	073900	10 E	6 W	3.0	325
21	055900	055900	62 E	55 E	1.0	298
23	063000	063000	17 W	11 E	2.0	246
25	050500	050500	16 W	46 W	3.0	223
26	052000	052000	39 W	2 E	2.0	223
28	035200	035200	48 E	64 E	4.0	249

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Table B3  
Reflected Signal Correlations for Fort Stewart, Satellite 1958 Delta 1

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Oct 1	062926	062900	74 W	73 W	0.3	176
1	151103	151310	28 E	34 E	3.6	668
4	051026	051343	67 W	23 W	0.2	179
4	153343	153400	48 W	58 W	7.0	660
5	143224	143430	18 E	11 W	0.1	665
6	044130	045145	52 W	52 W	2.8	175
8	143946	144435	90 W	66 W	0.1	646
9	133659	133827	7 E	23 W	0.1	652
12	025304	025730	66 E	38 E	0.2	183
13	032516	032545	58 W	71 W	0.2	185
13	120841	120400	79 E	28 E	0.3	638
16	114225	114640	32 W	16 W	0.4	619
17	015348	015937	73 W	40 W	1.4	180
18	105551	105500	9 E	17 E	0.2	620
19	110926	111508	27 W	38 W	3.0	613
20	012647	012245	81 W	51 W	0.2	187
21	102010	101825	36 E	35 E	0.1	612
21	114952	115510	71 W	80 W	2.0	608
22	001801	002420	19 W	6 W	0.6	180
23	102749	102918	27 W	59 W	5.0	602
26	091442	091500	22 W	35 W	2.0	570
28	230617	231015	90 W	80 W	0.2	177
29	074315	074418	38 E	47 E	0.8	565
29	091928	091810	90 W	70 W	0.2	555
30	074206	074015	5 E	23 E	2.8	562
30	091324	091517	59 W	77 W	0.4	528
31	073814	073448	11 W	3 W	3.2	521
31	090711	090924	90 W	84 W	0.1	519
Nov 1	073332	072621	53 W	11 W	0.2	522
1	090125	090121	90 W	83 W	0.2	522
2	071529	071629	6 E	24 W	0.1	515
3	070338	070338	76 W	30 W	0.2	507
5	063037	063138	87 W	22 W	2.0	489
6	063900	063127	62 W	51 W	0.5	480
6	201207	201637	26 W	13 W	3.0	186
7	061027	061327	87 W	58 W	0.2	470
8	060446	060431	46 W	53 W	2.0	485
9	054452	054327	61 W	50 W	0.5	477
9	192738	192537	44 W	5 W	1.5	188
10	052341	052031	89 W	43 W	0.2	469
11	044801	045538	90 W	30 W	0.4	466
11	183630	183423	67 E	50 E	0.2	184
12	042745	042744	88 W	8 W	0.4	458
13	190031	190358	78 W	77 W	1.0	189
14	045328	045357	90 W	72 W	0.2	440
15	025304	030443	90 E	43 E	0.2	421
15	045121	043755	90 W	81 W	1.5	418
15	180725	181256	79 W	77 W	0.3	182
16	040918	040257	73 W	73 W	0.2	403

Table B3 (Continued)  
Reflected Signal Correlations for Fort Stewart, Satellite 1958 Delta 1

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Nov 16	173734	173749	78 W	62 W	0.2	178
17	032443	032702	59 W	64 W	0.2	387
18	024216	024913	90 W	39 W	0.2	369
20	024751	025647	62 W	75 W	1.3	399
20	163115	162445	38 W	75 W	0.4	399
21	015900	021006	49 W	56 W	1.8	389
22	012214	012131	90 E	18 E	0.4	380
22	162100	161900	62 W	79 W	0.3	181
24	003401	005818	13 W	22 W	0.3	354
25	011914	013203	79 W	76 W	0.2	340
25	144758	144717	57 W	50 W	0.2	176
26	003533	002843	81 W	32 W	0.4	340
26	014003	013657	53 W	85 W	0.2	342
26	144503	144505	40 W	76 W	0.2	158

Table B4  
Reflected Signal Correlations for Fort Stewart, Satellite 1958 Delta 2

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Altitude (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Oct 2	070421	070530	64 W	70 W	1.2	152
5	060606	060700	17 W	37 W	1.0	151
6	062231	062215	76 W	76 W	3.2	154
10	144433	144440	12 W	26 W	1.2	918
13	042630	042845	71 W	69 W	1.6	155
16	032243	032155	07 E	24 W	1.2	167
17	033450	033355	64 W	72 W	1.6	171
20	022452	022525	02 W	13 W	0.8	180
21	132844	132835	90 W	66 W	0.4	929
22	024452	024730	90 W	82 W	1.0	186
23	120700	120555	68 W	49 W	20.0	936
Nov 2	231440	231520	22 W	35 W	1.6	237
5	084223	083500	53 W	21 W	1.6	941
7	215841	220010	73 W	24 W	2.2	241
9	084827	085310	40 W	70 W	0.6	936
13	073460	072420	25 W	57 W	0.2	944
13	203807	203745	17 W	38 W	1.2	246
15	054443	054705	14 E	3 E	0.6	954
16	055246	054940	5 W	16 W	0.3	954
17	055308	055125	9 W	33 W	0.5	939
19	041240	041255	24 E	45 E	0.2	970
19	190708	190630	30 W	30 W	1.0	244
24	172501	172420	9 E	49 E	0.1	250
Dec 9	015145	015020	86 W	77 W	0.3	951
15	123711	123600	4 E	2 E	2.0	286

Table B5  
Reflected Signal Correlations for Silver Lake, Satellite 1958 Delta 2

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Dec 10	145300	145305	47 W	54 W	1.0	270
11	014133	013910	11 W	69 W	0.7	953
11	235128	235020	79 W	15 W	0.3	955
18	121357	121148	47 E	48 E	1.6	295
19	120534	120310	40 E	38 E	1.5	300
20	115654	115500	65 E	25 E	2.0	321
20	210138	210000	84 E	45 E	1.0	936
20	224147	224100	3 E	53 W	2.0	930
23	112916	112900	1 W	22 W	1.6	337
24	202346	202200	83 E	21 E	2.0	941

Table B6  
Reflected Signal Correlations for Fort Stewart, Satellite 1958 Epsilon

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Oct 2	032854	033020	90 W	58 W	0.2	872
3	025642	025730	57 W	43 W	0.4	904
20	135128	135406	58 W	48 W	0.1	755
21	131131	131215	70 W	31 W	0.3	724
25	122347	122100	90 W	53 W	0.2	618
29	112859	112552	70 W	66 W	0.4	595
Nov 2	101853	101824	81 W	72 W	0.1	433
3	093618	093417	57 W	60 W	0.2	408
5	082516	080540	12 W	18 E	0.2	350
7	082735	083417	90 W	67 W	0.1	324
11	065723	071214	76 W	68 W	0.3	259
11	143338	143918	43 W	50 W	0.4	932
12	061615	061657	50 W	46 W	1.8	242
13	145322	144954	90 W	73 W	0.2	975
14	121827	121615	78 W	47 E	0.2	893
14	140347	140142	65 W	66 W	0.2	838
15	054443	054032	90 W	68 W	1.0	211
15	130723	131252	52 W	50 W	0.2	808
16	045339	045116	10 E	11 W	0.2	200
18	050707	045939	90 W	80 W	0.2	180
21	042105	041621	76 W	83 W	0.4	179
22	032245	032512	90 W	75 W	0.2	178
22	105614	105550	57 W	42 W	0.7	606
23	100554	100424	81 W	18 E	0.1	609
24	110239	105755	88 W	73 W	0.3	554
25	024523	023737	76 W	78 W	0.6	182
26	014535	014723	45 W	48 W	1.0	200

Table B7  
Reflected Signal Correlations for Silver Lake, Satellite 1958 Epsilon

Date (1958)	Universal Time (hr-min-sec)		Zenith Angle (Deg)		Signal Duration (Sec)	Predicted Height (Statute Miles)
	Observed	Predicted	Observed	Predicted		
Dec 6	054349	053900	83 E	83 E	0.2	315
6	230711	230122	75 E	40 W	0.8	299
6	230712	230122	1 W	40 W	0.3	299
8	210742	210834	15 E	54 E	0.1	340
10	210431	210300	30 E	47 E	0.7	369
11	212935	213424	47 W	57 W	1.6	378
13	193510	193600	29 E	65 E	0.1	441
12	211700	212200	26 W	63 W	1.0	460
13	212839	212200	66 W	63 W	0.6	460
14	202228	202218	53 W	25 W	0.4	445
15	035630	034923	13 W	20 W	0.3	191
16	025139	024954	50 E	77 E	2.0	191
22	012557	012300	52 E	30 E	1.5	179
22	164531	165000	23 E	48 E	2.0	654
28	153253	152700	44 E	11 E	6.0	794
29	141243	141700	60 E	54 E	0.8	813
29	155911	160300	21 W	41 W	0.6	785

APPENDIX C

Partial Records of 1958 Zeta Passes  
for December 1958

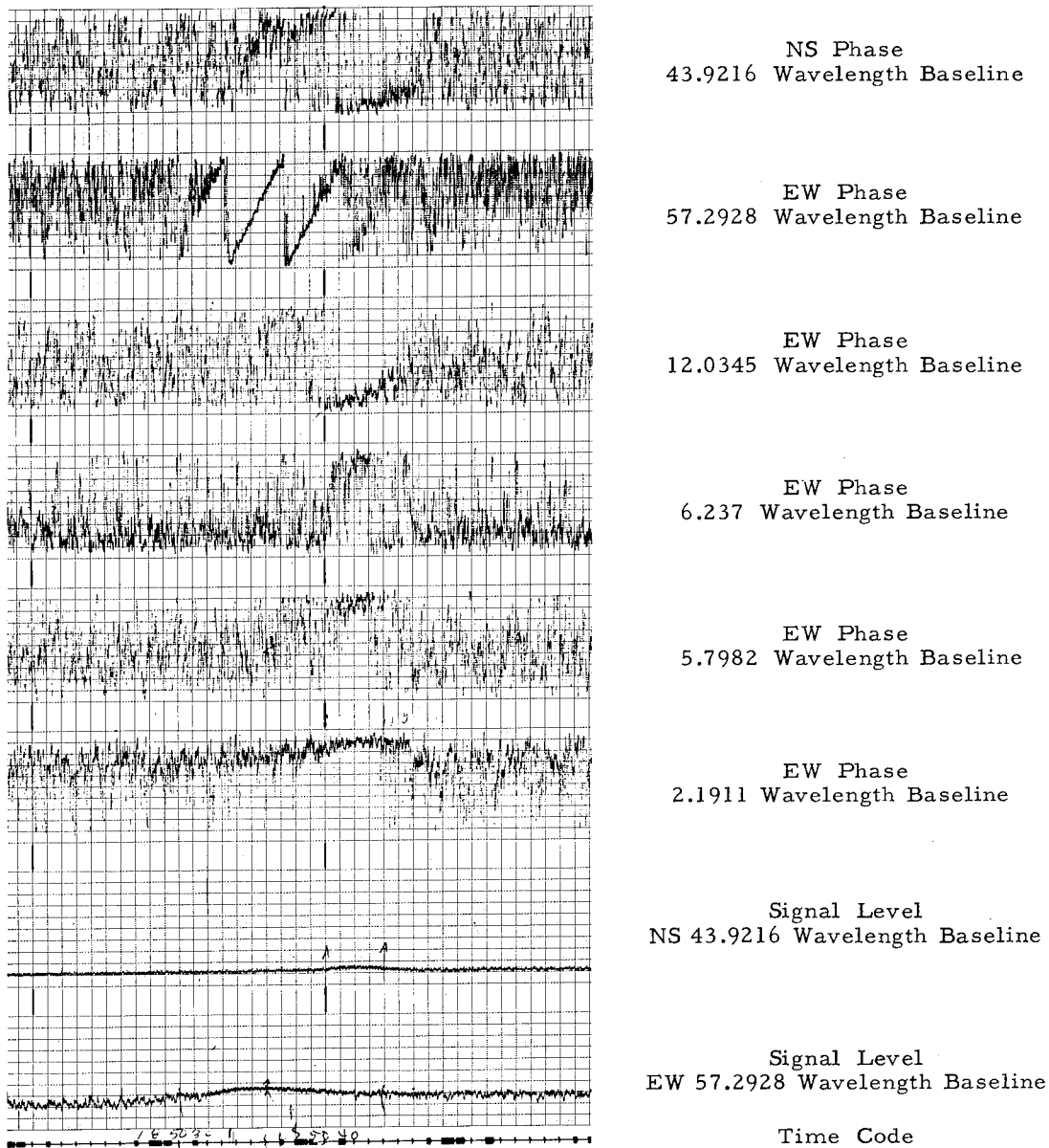
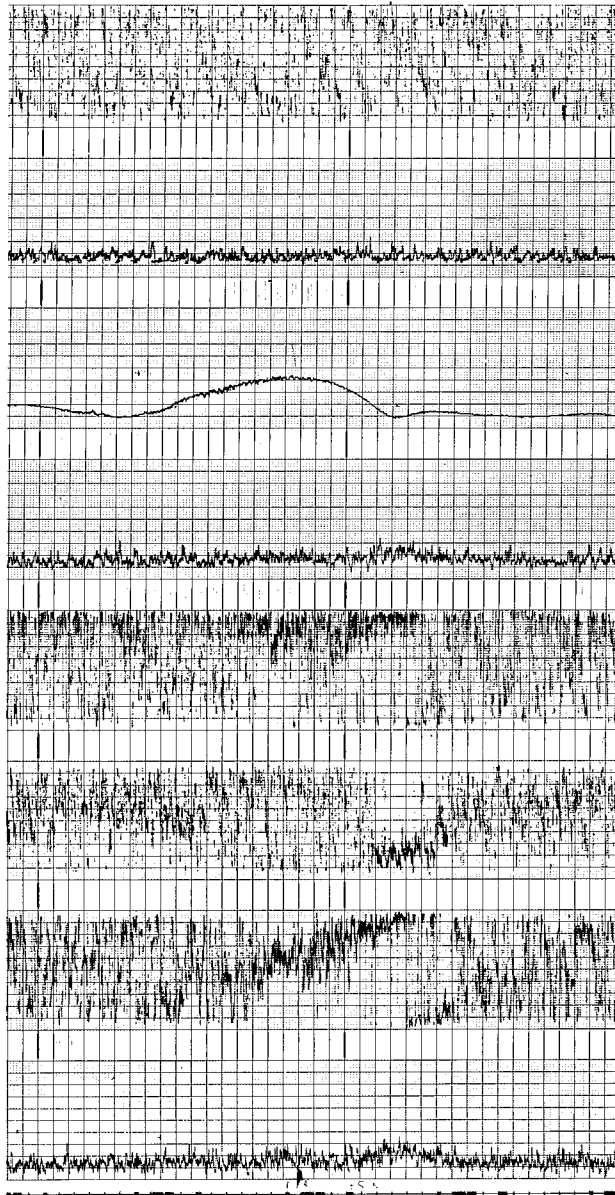


Fig. C1-a - Silver Lake record of 1958 Zeta pass at 185046 UT  
on December 23 at a height of 425 miles



Yagi Phase

Signal Level,  
Yagi

Signal Level, Noise  
Correlation Channel,  
107.97 Mc

Signal Level,  
2.6795 Wavelength Baseline

EW Phase  
2.6795 Wavelength Baseline

EW Phase  
3.1187 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

Signal Level  
5.7982 Wavelength Baseline

Time Code

Fig. C1-b - Fort Stewart record of 1958 Zeta pass at 185046 UT  
on December 23 at a height of 425 miles

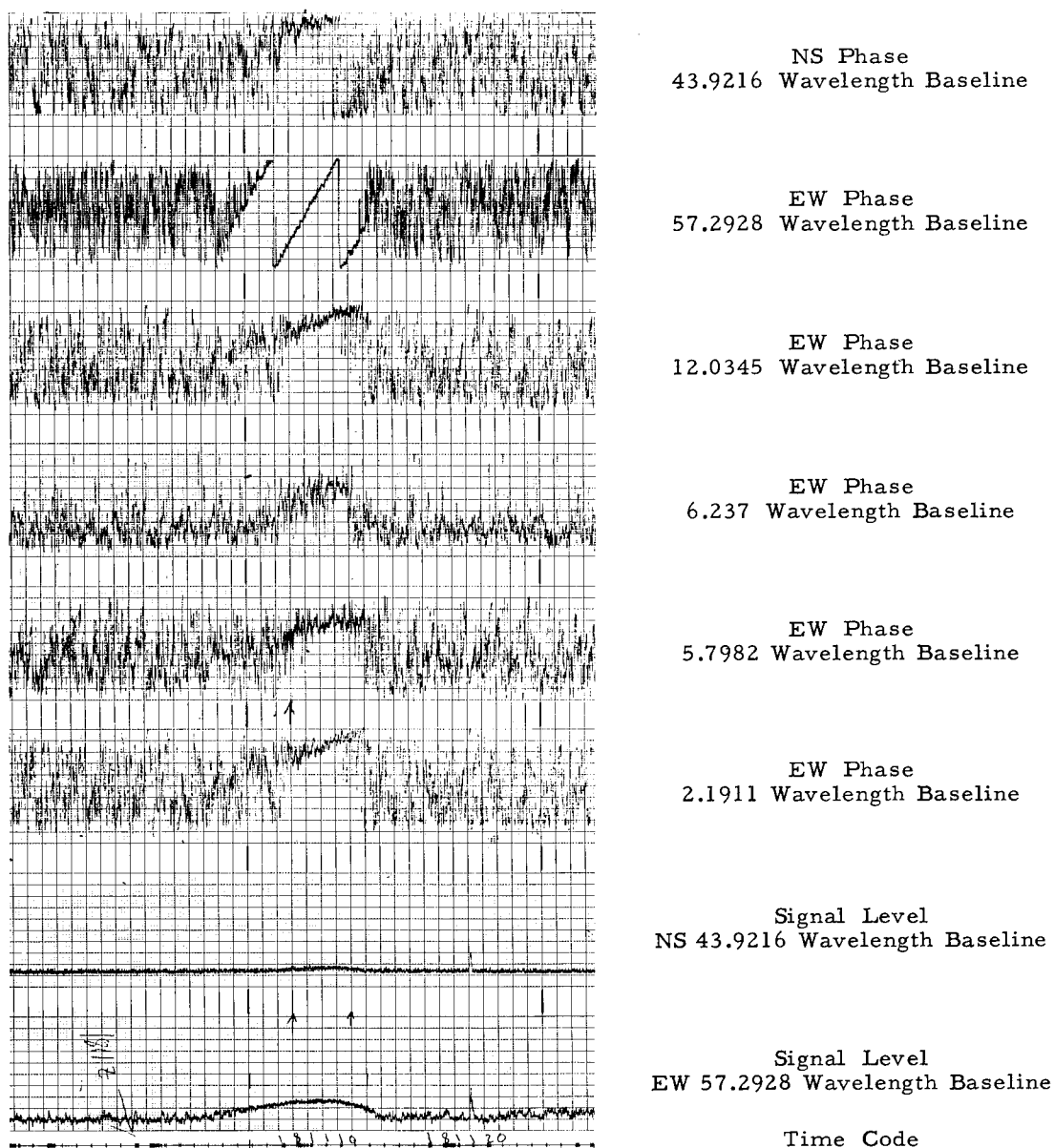


Fig. C2-a - Silver Lake record of 1958 Zeta pass at 181114 UT  
on December 24 at a height of 470 miles

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Yagi Phase

Signal Level,  
Yagi

Signal Level, Noise  
Correlation Channel,  
107.97 Mc

Signal Level,  
2.6795 Wavelength Baseline

EW Phase  
2.6795 Wavelength Baseline

EW Phase  
3.1187 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

Signal Level  
5.7982 Wavelength Baseline

Time Code

Fig. C2-b - Fort Stewart record of 1958 Zeta pass at 181114 UT  
on December 24 at a height of 470 miles

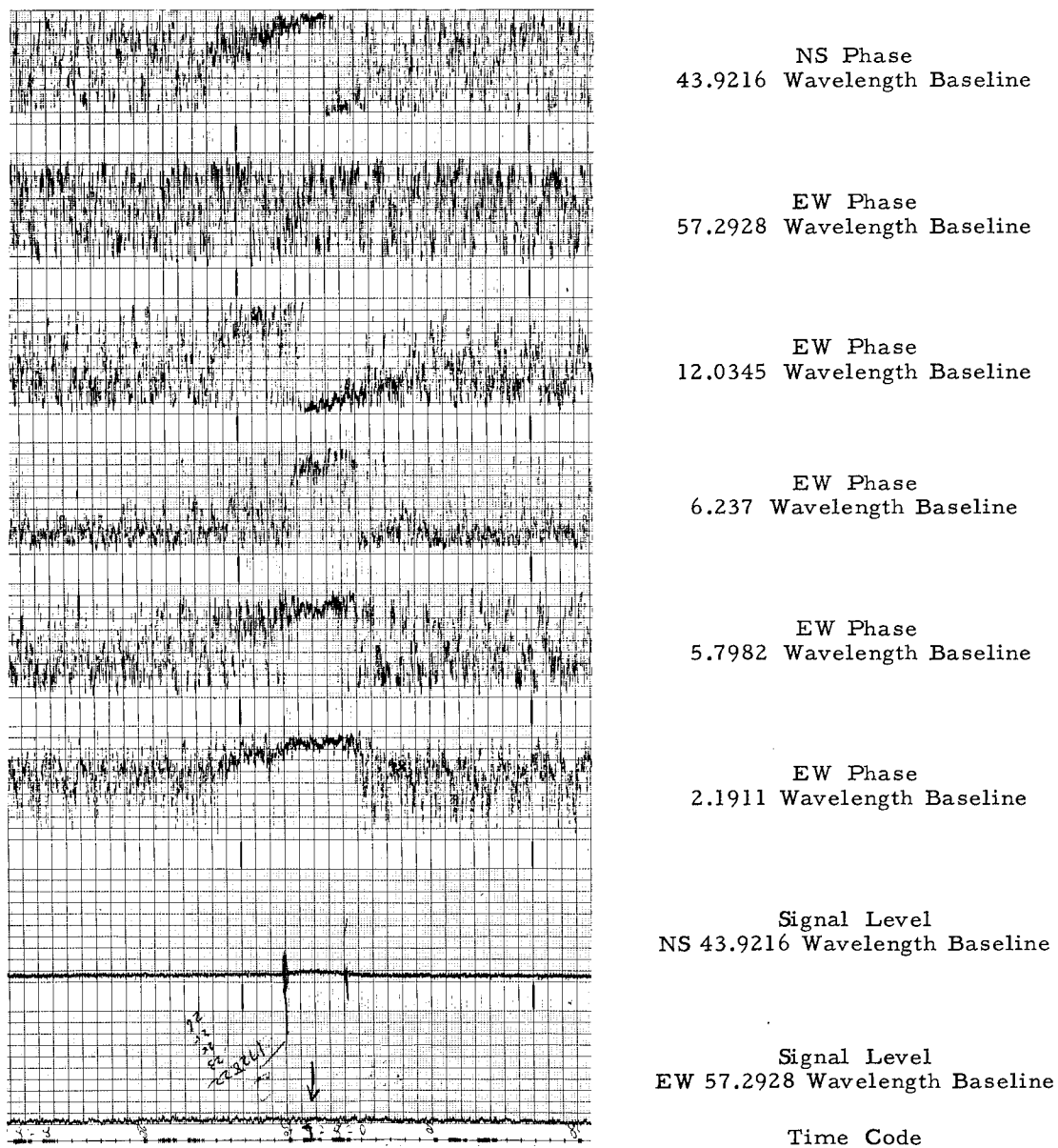


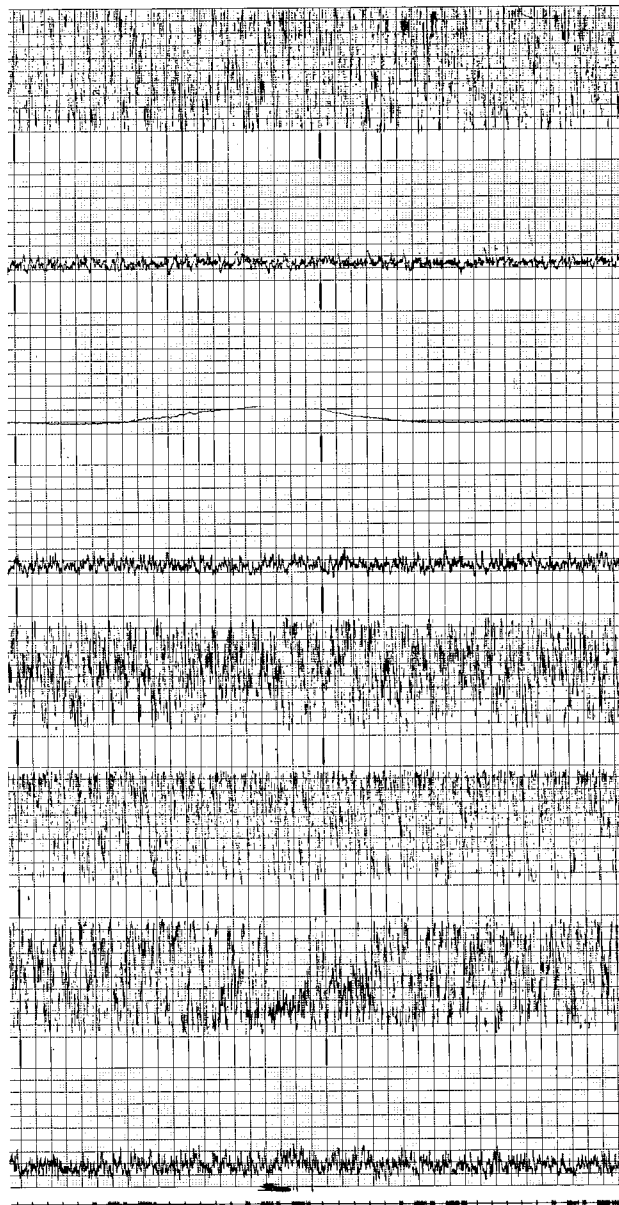
Fig. C3-a - Silver Lake record of 1958 Zeta pass at 172824 UT  
on December 25 at a height of 540 miles

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Yagi Phase

Signal Level,  
Yagi

Signal Level, Noise  
Correlation Channel,  
107.97 Mc

Signal Level,  
2.6795 Wavelength Baseline

EW Phase  
2.6795 Wavelength Baseline

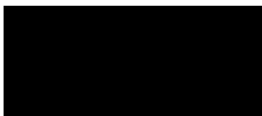
EW Phase  
3.1187 Wavelength Baseline

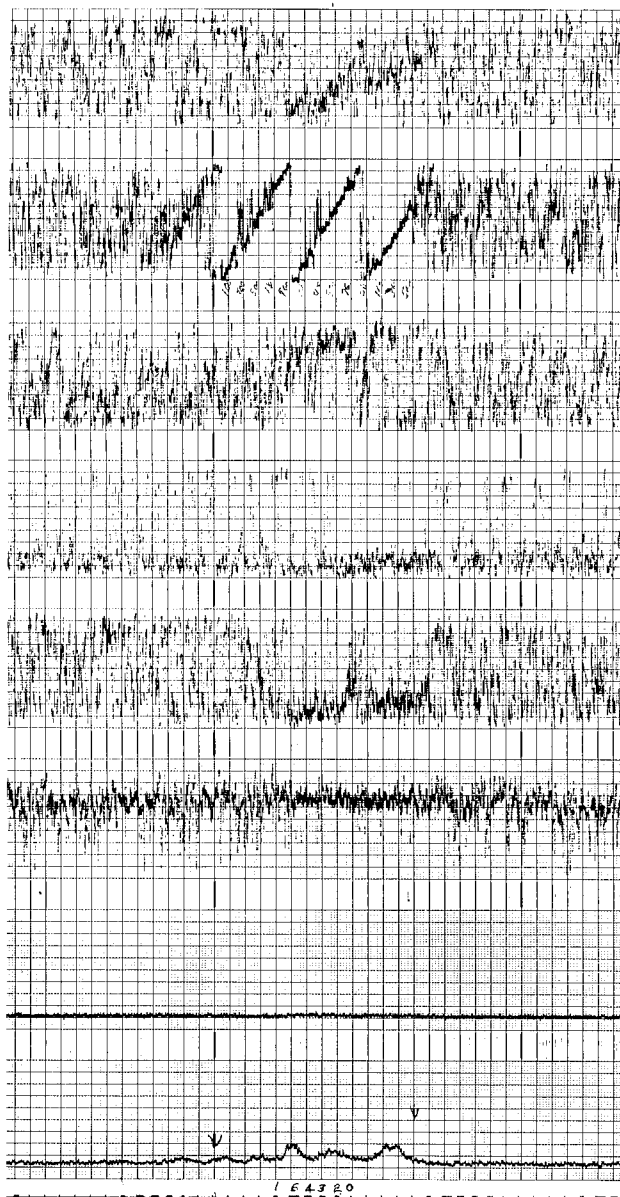
EW Phase  
5.7982 Wavelength Baseline

Signal Level  
5.7982 Wavelength Baseline

Time Code

Fig. C3-b - Fort Stewart record of 1958 Zeta pass at 172824 UT  
on December 25 at a height of 540 miles





NS Phase  
43.9216 Wavelength Baseline

EW Phase  
57.2928 Wavelength Baseline

EW Phase  
12.0345 Wavelength Baseline

EW Phase  
6.237 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

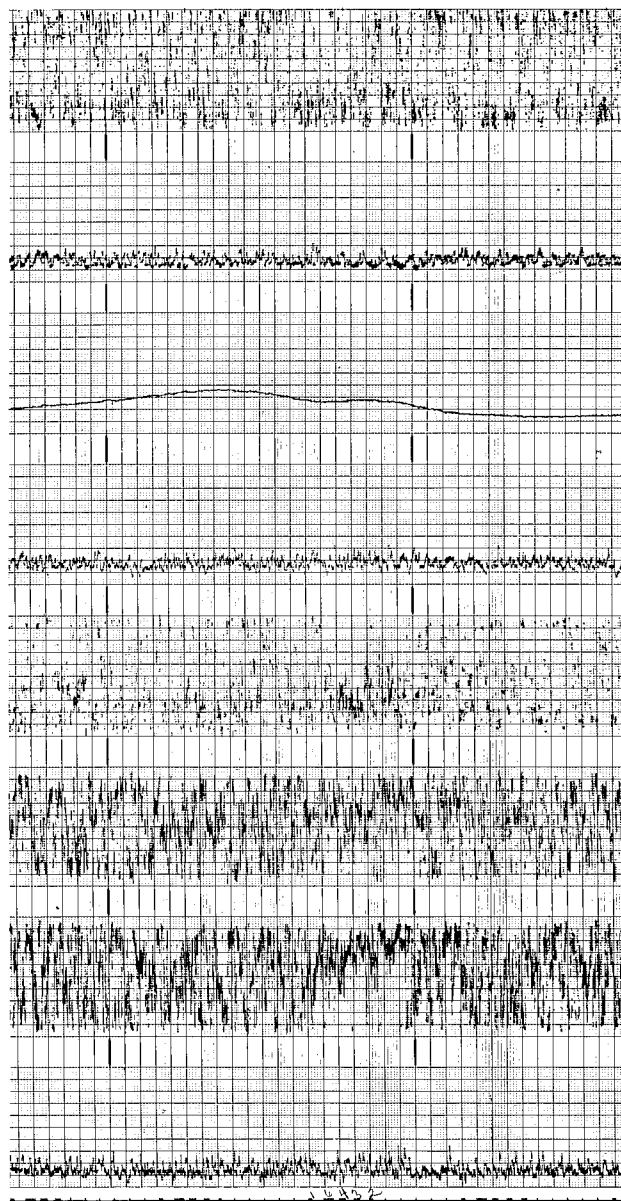
EW Phase  
2.1911 Wavelength Baseline

Signal Level  
NS 43.9216 Wavelength Baseline

Signal Level  
EW 57.2928 Wavelength Baseline

Time Code

Fig. C4-a - Silver Lake record of 1958 Zeta pass at 164324 UT  
on December 28 at a height of 755 miles



Yagi Phase

Signal Level  
Yagi

Signal Level, Noise  
Correlation Channel,  
107.97 Mc

Signal Level,  
2.6795 Wavelength Baseline

EW Phase  
2.6795 Wavelength Baseline

EW Phase  
3.1187 Wavelength Baseline

EW Phase  
5.7982 Wavelength Baseline

Signal Level  
5.7982 Wavelength Baseline

Time Code

Fig. C4-b - Fort Stewart record of 1958 Zeta pass at 164324 UT  
on December 28 at a height of 755 miles